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SMOKED MEATS

II. DEVELOPMENT OF RANCIDITY IN SMOKED AND UNSMOKED WILTSHIRE BACON DURING STORAGE[1]

BY W. HAROLD WHITE[2]

Abstract

Spoilage in the fat of smoked and unsmoked Wiltshire backs and gammons, stored at temperatures of −18°, −9°, −1°, and 7° C. for approximately four months, was assessed by determinations of peroxide oxygen and free fatty acid contents. Smoked bacon can be stored satisfactorily for at least two months at −1° to −18° C. whereas unsmoked bacon was usually rancid after one month. Spoilage due to the formation of excessive quantities of free fatty acids was found to be of little importance.

Introduction

There is normally little occasion for the storage of Canadian Wiltshire bacon in England since it is usually consumed within a relatively short period after its arrival. However, such a need may occur during the war period. Consequently, it is essential that adequate information be available on the most suitable storage conditions. While bacon is less susceptible to protein spoilage than pork, the curing salts normally employed in its manufacture have a pro-oxidant effect on the fat and tend to hasten the development of rancidity. It has been shown previously that both slime formation and fat spoilage can be materially retarded by smoking the bacon prior to storage (5). The investigation reported here was undertaken to determine the effect of storage temperature and of smoking on the quality of Wiltshire backs and gammons.

Peroxide oxygen and free fatty acid formation in the fat, and bacterial growth and the colour and colour stability of the lean meat, were used as criteria of quality. Data on the bacteriological and colour measurements will be reported in subsequent papers.

Material and Methods

The investigation was divided into two parts. In the first, the material consisted of the right and left sides of four hogs, selected for uniformity in size and quality. After cure the sides were allowed to drain and partially

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Contribution from the Division of Applied Biology, National Research Laboratories, Ottawa, Canada. Issued as Paper No. 113 of the Canadian Committee on Food Preservation and as N.R.C. No. 1219.

[2] *Formerly, Biochemist, Food Investigations; at present, Director of Research, F. W. Horner Limited, Montreal, Que.*

mature for five days at 3.3° C. (38° F.), and the back and gammon were removed from each side. After allotting two backs at random to each of the storage temperatures of −18°, −9°, −1°, and 7° C. (0°, 15°, 30°, and 45° F.), each back was divided into two approximately equal portions, one of which was smoked at an air temperature of approximately 60° C. (140° F.) for 14 hr. This permitted a comparison to be made, with the same side, of the effect of smoking on changes during storage.

In order to minimize differences due to position, and the period to which any one cut surface was exposed during storage, each half back was subsequently divided into five equal portions, one of which, selected at random, was removed for study after the desired storage period. Prior to storage each of the five subsamples were pressed closely together, and the sample as a whole wrapped in sterile brown paper to minimize surface bacterial contamination. Desiccation during storage was minimized by storing the product in loosely closed metal containers.

The relative susceptibility to spoilage of the fat of backs and gammons was determined by smoking one gammon from each of the four hogs under the conditions described previously. Two gammons, one smoked and one unsmoked from the same hog, were held at each of the storage temperatures. This permitted a direct comparison to be made of the effect of smoking on material from the same hog. Prior to storage each gammon was divided into five subsamples and otherwise treated similarly to the backs.

The second part of the investigation was undertaken to determine if the size of the piece of bacon smoked had any effect on its subsequent storage behaviour. The relatively greater surface to volume ratio in small pieces might reasonably affect the rate of heat transfer, the extent of smoke deposition and the degree of desiccation of the meat. To permit this comparison the entire right and left sides of eight hogs were smoked under the conditions described previously, the backs removed, and each divided into six pieces for study during storage. Two smoked and the corresponding two unsmoked backs from the same hogs were held at each of the four storage temperatures. This permitted comparison of the effect of smoking on changes during storage in the fats of backs from the same hog.

Oxidative and hydrolytic changes in the fat were assessed from the peroxide oxygen and free fatty acid contents, respectively. Previous reference has been made to the methods employed (4). These determinations were made on the fat of both smoked and unsmoked half-backs and of gammons after 21, 42, 70, and 98 days for product stored at −1°, −9°, and −18° C., and after 11, 21, 32, and 42 days for product held at 7° C. In studying the effect of the size of the cut smoked, peroxide oxygen determinations alone were made on the back fat at the times mentioned above, and in addition after 130 days' storage at −1°, −9°, and −18° C. and 71 days at 7° C.

Results

Peroxide Oxygen Formation

Back Fat

The results obtained for peroxide oxygen formation in the fat of both small cuts and whole backs of smoked and unsmoked Wiltshire bacon during storage are given in Table I as average values for each treatment over all others studied. Because of the differences in sampling times it is to be noted that direct comparisons cannot be made between the data obtained for 7° C. and those for the lower temperatures, nor between small cuts and whole backs.

TABLE I

MEAN VALUES FOR THE EFFECT OF STORAGE PERIOD, TEMPERATURE, AND SMOKING ON PEROXIDE OXYGEN FORMATION IN THE FAT OF WILTSHIRE BACK BACON

Temperature

°C.	7	−1	−9	−18
Mean peroxide oxygen content of:				
Small cuts[1, 2]	3.9	4.7	4.9	6.4
Whole backs [1, 2]	5.3	10.9	11.9	6.7

Smoking

Treatment	Smoked	Unsmoked
Mean peroxide oxygen content of:		
Small cuts[1]	2.8	7.8
Small cuts[2]	1.2	6.6
Whole backs[1]	5.9	13.7
Whole backs[2]	3.8	6.8

Storage period

Days	0	11	21	32	42	70	98	130
Mean peroxide oxygen content of:								
Small cuts[1]	0.88	—	1.9	—	5.2	7.1	11.5	—
Small cuts[2]	0.84	2.1	2.4	8.2	5.9	—	—	—
Whole backs[1]	0.84	—	0.96	—	7.7	12.3	17.5	19.7
Whole backs[2]	0.94	1.2	1.8	2.9	2.0	23.2	—	—

[1] *Mean, as ml. 0.002 N sodium thiosulphate over all other conditions studied for product stored at −1°, −9°, and −18° C.*

[2] *As for* [1], *but on data obtained at 7° C. only.*

While peroxide oxygen formation usually proceeded at a slower rate at the lower storage temperatures, the differences between the mean values at the various temperatures were small.

Smoking was very effective in retarding the development of rancidity in back fat. Examination of the detailed data shows that at all temperatures the unsmoked fat was usually slightly or definitely rancid after 21 to 42 days' storage, whereas that of most of the smoked bacon was in a satisfactory condition after 42 to 70 days. This behaviour is in marked contrast to that of pork for which it has been shown that a temperature of −18° C. gives satisfactory protection for 48 weeks (2, 3).

The mean peroxide oxygen content increased progressively with the storage period. The results indicate that, on the average, the induction period of peroxide oxygen formation was between 21 and 42 days.

While the small cuts and the entire backs of smoked bacon behaved generally in a comparable manner, peroxide oxygen formation was greater in the fat of entire backs. However, the differences were not statistically significant. Possible factors contributing to this behaviour, such as differences in the extent of smoke deposition, etc., have been mentioned in the preceding discussion.

Details of the effect of storage temperature and time on peroxide oxygen formation in the fat of both smoked and unsmoked back bacon are illustrated in Fig. 1. In its preparation the data for the two experiments were averaged in order to present the most reliable information. From this it may be seen that, even when smoked and stored at −18° C., incipient oxidative rancidity

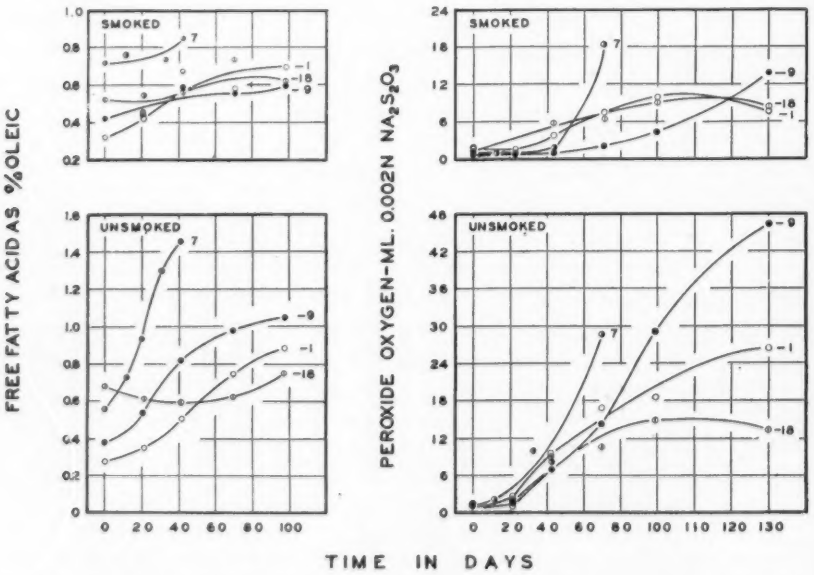

FIG. 1. *Peroxide oxygen and free fatty acid formation in the fat of smoked and unsmoked back bacon during storage at 7°, −1°, −9°, and −18° C.*

was evident in back bacon after a period of 40 to 70 days. The reasons for the variable behaviour with temperature are unknown.

The data for the peroxide oxygen content of the back fat could not be used directly for statistical analysis because of the variable manner in which different sides responded to the same treatment. This difficulty was overcome by transforming the data to the corresponding logarithms prior to analysis (1). The results of such analyses showed that smoking and the storage period were the most important factors studied for both small cuts and whole backs. The significant difference between hogs, observed for product stored at 7° C., is presumably due to inherent variations and not to experimental treatment since the material within each experiment was smoked at the same time and under the same conditions.

TABLE II

ANALYSES OF VARIANCE FOR THE EFFECT OF STORAGE PERIOD, TEMPERATURE, AND SMOKING ON PEROXIDE OXYGEN FORMATION IN THE FAT OF WILTSHIRE BACK BACON

Source of variance	Small cuts		Whole backs	
	D.f.	Mean sq.	D.f.	Mean sq.
Material stored at −1°, −9°, and −18° C.				
Temperature	2	0.799	2	0.337
Between hogs within temperature	3	0.136	3	0.170
Smoking	1	3.80**	1	2.98**
Smoking × temperature	2	0.185	2	0.449*
Smoking × between hogs within temperature	3	0.032	3	0.015
Time	3	1.91**	5	8.26**
Time × temperature	6	0.215	10	0.195**
Time × smoking	3	0.517*	5	0.226**
Time × temperature × smoking	6	0.161	10	0.096*
Residual	18	0.153	30	0.034
Analytical error	48	0.002	72	0.005
Material stored at 7° C.				
Smoking	1	3.42**	1	0.860*
Between hogs	1	0.405*	1	0.533*
Time	3	0.195	5	2.06**
Time × smoking	3	0.548**	5	0.089
Residual	7	0.052	11	0.109
Analytical error	16	0.002	24	0.002

* *Indicates 5% level of significance.*
** *Indicates 1% level of significance.*

Gammon Fat

The effect of the various factors studied on peroxide oxygen formation in the fat of gammons was similar to that described for the backs (Table III). The results of analyses of variance of the data are given in Table IV. It is

TABLE III

MEAN VALUES FOR THE EFFECT OF STORAGE PERIOD, TEMPERATURE, AND SMOKING ON PEROXIDE OXYGEN FORMATION IN THE FAT OF WILTSHIRE GAMMONS

Temperature

° C.	7	−1	−9	−18
Mean peroxide oxygen content[1, 2]	2.1	4.4	2.5	14.3

Smoking

Treatment	Smoked	Unsmoked
Mean peroxide oxygen content[1]	4.0	10.1
Mean peroxide oxygen content[2]	0.84	3.34

Storage period

Days	0	11	21	32	42	70	98
Mean peroxide oxygen content[1]	0.89	—	1.7	—	9.4	7.9	15.5
Mean peroxide oxygen content[2]	0.87	1.3	0.84	1.1	6.4	—	—

[1] *Mean, as ml. 0.002 N sodium thiosulphate, over all other conditions studied for product stored at −1°, −9°, and −18° C.*

[2] *As for [1], but on data obtained at 7° C. only.*

to be recalled that the smoked and unsmoked gammons studied at each temperature were from the same hog. Consequently, the observed differences with temperature also include variations between gammons from different hogs. Thus, inherent differences in the stability of the fat from different hogs may possibly account for the abnormally high values obtained at −18° C. Other than this, back and gammon fat behaved generally in a comparable manner during storage. Smoking caused a marked retardation in peroxide oxygen formation, and thus gives protection from spoilage to the fat of both backs and gammons.

FREE FATTY ACID FORMATION

Back Fat

The mean free fatty acid content of back fat was usually small (Table V), indicating that spoilage due to the formation of excessive quantities of free fatty acids during storage is of little importance. A similar behaviour was

TABLE IV

ANALYSES OF VARIANCE FOR THE EFFECT OF STORAGE PERIOD, TEMPERATURE, AND SMOKING ON PEROXIDE OXYGEN FORMATION IN THE FAT OF WILTSHIRE GAMMONS

Source of variance	D.f.	Mean sq.
Material stored at −1°, −9°, and −18° C.		
Temperature	2	809
Smoking	1	559
Smoking × temperature	2	57.9
Time	4	433*
Time × smoking	4	115*
Time × temperature	8	136*
Residual	8	26.8
Analytical error	30	0.397
Material stored at 7° C.		
Smoking	1	31.4
Time	4	22.9
Time × smoking	4	21.1
Analytical error	10	0.353

* *Indicates 5% level of significance.*

TABLE V

MEAN VALUES FOR THE EFFECT OF STORAGE PERIOD, TEMPERATURE, AND SMOKING ON FREE FATTY ACID FORMATION IN THE FAT OF WILTSHIRE BACK BACON

Temperature

° C.	7	−1	−9	−18
Mean free fatty acid content[1, 2]	0.86	0.55	0.64	0.62

Smoking

Treatment	Smoked	Unsmoked
Mean free fatty acid content[1]	0.54	0.66
Mean free fatty acid content[2]	0.71	1.01

Storage period

Days	0	11	21	32	42	70	98
Mean free fatty acid content[1]	0.43	—	0.47	—	0.63	0.71	0.77
Mean free fatty acid content[2]	0.63	0.75	0.74	1.03	1.15	—	—

[1] *Mean, as % oleic acid, over all other conditions studied for product stored at −1°, −9°, and −18° C.*

[2] *As for [1], but on data obtained at 7° C. only.*

observed for pork fat (2, 3). The mean acid content showed some tendency to increase with increase in storage temperature but the differences were small. Smoking resulted in a slightly lower mean value of free fatty acid. This is presumably due to the retardation by smoking of the agencies responsible for both oxidation and hydrolysis of the fat. Of the periods studied the increase in free fatty acid content was on the average relatively greatest between 21 and 42 days. It should be recalled that the stage of rapid formation of peroxide oxygen also occurred within this period. Further details on the effect of the factors studied on free fatty acid formation may be seen in Fig. 1.

The results of an analysis of variance (Table VI) showed that storage time only had a significant effect on the formation of free fatty acids at temperatures of −1°, −9°, and −18° C. However, at 7° C. differences in the free fatty acid content attributable to smoking, time in storage, and variations in sides reached the level of statistical significance.

TABLE VI

ANALYSES OF VARIANCE FOR THE EFFECT OF STORAGE PERIOD, TEMPERATURE, AND SMOKING ON FREE FATTY ACID FORMATION IN THE FAT OF WILTSHIRE BACK BACON

Source of variance	D.f.	Mean sq.
Material stored at −1°, −9°, and −18° C.		
Temperature	2	0.085
Between hogs within temperature	3	0.256
Smoking	1	0.417
Smoking × temperature	2	0.101
Smoking × between hogs within temperature	3	0.117
Time	4	0.520*
Time × temperature	8	0.061
Time × smoking	4	0.056
Time × temperature × smoking	8	0.053
Residual	24	0.101
Analytical error	60	0.004
Material stored at 7° C.		
Smoking	1	0.859**
Between hogs	1	1.63**
Time	4	0.381*
Time × smoking	4	0.236
Residual	9	0.077
Analytical error	20	0.001

* *Indicates 5% level of significance.*
** *Indicates 1% level of significance.*

TABLE VII

MEAN VALUES FOR THE EFFECT OF STORAGE PERIOD, TEMPERATURE, AND SMOKING ON FREE FATTY ACID FORMATION IN THE FAT OF WILTSHIRE GAMMONS

Temperature

° C.	7	−1	−9	−18
Mean free fatty acid content[1, 2]	0.57	0.59	0.77	0.54

Smoking

Treatment	Smoked	Unsmoked
Mean free fatty acid content[1]	0.67	0.59
Mean free fatty acid content[2]	0.63	0.51

Storage period

Days	0	11	21	32	42	70	98
Mean free fatty acid content[1]	0.42	—	0.45	—	0.72	0.70	0.85
Mean free fatty acid content[2]	0.37	0.44	0.53	0.62	0.88	—	—

[1] *Mean, as % oleic acid, over all other conditions studied for product stored at −1°, −9°, and −18° C.*

[2] *As for [1], but on data obtained at 7° C. only.*

TABLE VIII

ANALYSES OF VARIANCE FOR THE EFFECT OF STORAGE PERIOD, TEMPERATURE, AND SMOKING ON FREE FATTY ACID FORMATION IN THE FAT OF WILTSHIRE GAMMONS

Source of variance	D.f.	Mean sq.
Material stored at −1°, −9°, and −18° C.		
Temperature	2	0.296
Smoking	1	0.117
Smoking × temperature	2	0.046
Time	4	0.406*
Time × smoking	4	0.007
Time × temperature	8	0.106**
Residual	8	0.016
Analytical error	30	0.001
Material stored at 7° C.		
Smoking	1	0.069
Time	4	0.157
Time × smoking	4	0.026
Analytical error	10	0.002

* *Indicates 5% level of significance.*

** *Indicates 1% level of significance.*

Gammon Fat

The mean free fatty acid content of the fat of the gammons was, like that of the backs, low and somewhat variable (Table VII). Variations in storage temperature had little effect. In contrast to the backs, the mean free fatty acid content of smoked gammon fat was greater than that of the unsmoked. The reason for this is not apparent. The greatest increase with time was again observed to occur between 21 and 42 days' storage. An analysis of variance indicated that the only statistically significant variables were storage period and the differential effect of temperature at different storage times (Table VIII).

Acknowledgment

The author wishes to thank Dr. J. W. Hopkins, Statistician, National Research Laboratories, for his advice and aid with the statistical computations.

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SMOKED MEATS

III. EFFECT OF MATURATION PERIOD ON QUALITY[1]

By W. Harold White[2], A. H. Woodcock[3], and N. E. Gibbons[4]

Abstract

Wiltshire-cured sides were matured at −1.1° C. (30° F.) for periods of 1 to 25.5 days prior to smoking at 60° C. (140° F.). The effect of the length of the maturation period on quality was assessed by flavour tests; and by determination of surface bacterial growth, peroxide oxygen formation in the fat, and changes in colour and colour stability of the lean meat during storage at −1.1° C. subsequent to smoking.

By all criteria of quality used, differences attributable to variations in the length of the maturation period were usually small and showed no consistent trend. However, there was some indication that a maturation period of about 10 to 15 days was most suitable.

Introduction

The results of extensive investigations on the flavour of Canadian Wiltshire bacon (9, 10) showed that the English consumer would prefer a product containing less salt than that supplied prior to the war. Subsequent studies indicated that a milder cured bacon, when smoked, would be in a satisfactory condition after shipment to England (8), and that smoking materially retarded the development of rancidity in bacon fat (7). With such information available on the desirability of smoking bacon prepared for export purposes, it was believed important to determine the most suitable time after cure for doing this, i.e. the length of the maturation period. The present paper describes an investigation to determine the effect of maturation period on flavour quality of Wiltshire backs and gammons and on surface bacterial growth, colour changes, and development of rancidity in the fat during storage after smoking.

The period of maturation is believed to improve the quality of the product, especially with respect to colour uniformity and stability, and the development of the typical bacon flavour. Little is known concerning the actual nature of the changes occurring. However, these presumably include alterations in the protein constituents and greater uniformity in the distribution of the curing salts. Moreover, it is generally considered that such changes are either retarded or prevented after bacon is smoked.

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[2] *Formerly Biochemist, Food Investigations; at present Director of Research, F. W. Horner Limited, Montreal, Que.*

[3] *Formerly Biophysicist, Food Investigations. Now Research Chemist, E. S. & A. Robinson (Canada) Ltd., Toronto, Ont.*

[4] *Bacteriologist, Food Investigations.*

Materials and Procedure

The right and left sides of 16 hogs of uniform size and good quality were pumped and cured for nine days according to regular commercial practice. After cure, the sides were drained at about 4.4° C. (40° F.) for one day, wiped, divided into groups of four at random, baled, and stored at −1.1° C. (30° F.). One bale was removed from storage after each of 1, 4.5, 8, 11.5, 15, 18.5, 22, and 25.5 days from cure. The backs and gammons were removed from the sides and without washing or soaking were smoked at an air temperature of 60° C. (140° F.) for approximately 18 hr.

Bacteriological Measurements

The effect of smoking on surface bacterial content was determined by making counts before and after smoking on the rib surfaces of the sides matured for 1, 11.5, 18.5, and 25.5 days from cure.

To obtain information on the effect of maturation period on subsequent keeping quality a portion approximately 6 in. in length was taken from the front end of each back after smoking, wrapped in sterile, brown paper and stored at −1.1° C. in loosely covered containers. Surface bacterial counts were made on these samples after 29, 55, 97, and 139 days from cure. The procedures followed for securing and preparing the meat samples for bacteriological examination have been described (4).

Measurement on Fat

The peroxide oxygen content of the fat of the small cuts of bacon mentioned above was determined (6) at the same intervals during storage as the surface bacterial counts.

Colour Measurements

Colour measurements were made on portions approximately 6 in. in length taken from the rear of each back after smoking, after 25.5 days from cure, and finally after 30 days' storage at −1.1° C. from time of smoking. The determinations were made with a photoelectric colour comparator described previously (11, 12). Moreover, an estimate of colour stability was obtained by exposing the sample, after the initial measurement, to the atmosphere for 70 hr. at 7.1° C. (45° F.) and remeasuring the colour.

Flavour Tests

Flavour tests were made on both backs and gammons. The ribs and all bones were removed from the backs, and the shank bone from the gammons. Slices of the back (0.15 in. thick) and of the gammon (about 0.38 in. thick) were removed from the front or rear positions at random. The samples of back and gammon were prepared for tasting by grilling at 232° C. (450° F.) for six and eight minutes, respectively. When not required the gammons and backs were doubly wrapped in waxed paper and overwrapped with brown, and stored at −1.1° C.

The flavour tests were made progressively throughout the experiment in such a manner that the group of sides representing any particular maturation

period were compared, after smoking, with all groups matured for shorter periods. For example, in the first set of tests the 1- and 4.5-day groups were compared; in the second set, the 1-, 4.5-, and 8-day groups, etc., thus giving seven different sets in all. In addition, the final set of comparisons, which included all maturation periods, was repeated after storage of the backs for 17 and 36 days at −1.1° C.

An outline of the design of the various sets of flavour tests is given in Table I. Further details may be obtained from Fisher (3). In each set of tests the selection of the backs and gammons for the maturation periods compared was at random, except that each side within any one period was represented at least once. Tests on the backs and gammons were made on successive mornings. A member of the panel who tasted any particular combination of backs also tasted the same combination of gammons.

TABLE I

DESIGN OF FLAVOUR TESTS ON WILTSHIRE BACON MATURED FOR VARIOUS PERIODS AT −1.1° C.

Maturation periods[1] compared	Design of experiment	Number of tasters	Number of different combinations of maturation periods	Number of samples compared in any one combination
1, 4.5	Complete block	6	1	2
1, 4.5, 8	Complete block	6	1	3
1, 4.5, 8, 11.5	Duplicated, incomplete block	8	4	3
1, 4.5, 8, 11.5, 15	Single, incomplete block	10	10	3
1, 4.5, 8, 11.5, 15, 18.5	Single, incomplete block	10	10	3
1, 4.5, 8, 11.5, 15, 18.5, 22	Duplicated, incomplete block	14	7	3
1, 4.5, 8, 11.5, 15, 18.5, 22, 25.5	Single, incomplete block	14	14	4

[1] *Time in days from removal of bacon from cure to smoking.*

The members of the panel, consisting of male employees of these laboratories, were required merely to place the samples in order of preference, giving, where possible, reasons for the preference. The tasters were permitted to function in their own manner, and were free to state that no distinction was possible between any two or more samples. Cold water was provided for each taster and most took advantage of it.

Numerical values were assigned to the preference ratings so that the intervals between successive scores were such as to transfer the ordinal numbers obtained in scoring to normal deviates amenable to analysis of variance (3). Thus, for comparisons between two samples these were +0.56 and −0.56; for three samples +0.85, 0, and −0.85; and for four samples, 1.03, 0.30, −0.30, and −1.03. If any two or more samples were indistinguishable, each was assigned the average of the scores corresponding to the positions occupied by these samples in the order of preference.

Results

Bacterial Growth

Surface bacterial growth between the time of wiping and smoking of the sides was small and, within the limits studied, was independent of the length of this period (Table II). Smoking markedly reduced the surface counts, in agreement with a previous observation (8). However, the length of the maturation period had no apparent systematic effect on the extent of bacterial reduction when the sides were smoked.

TABLE II

EFFECT OF SMOKING ON SURFACE BACTERIAL COUNTS OF BACON MATURED FOR VARIOUS PERIODS AT −1.1° C.

Maturation period, days	Log_{10} of number of organisms per sq. cm.[1]		
	After wiping	Before smoking	After smoking
1	4.11	4.11	1.43
11.5	4.70	4.81	0.90
18.5	4.60	4.77	0.93
25.5	4.42	4.50	2.19

Analysis of variance[2]

Source of variance	D.f.	Mean square
Maturation period	3	0.552
Error	12	0.421
Smoking	1	81.186**
Smoking × maturation period	3	1.304**
Error	12	0.194

[1] *Mean values for four sides.*

[2] *On data obtained before and after smoking only.*

** *Exceeds 1% level of statistical significance.*

Mean values and an analysis of variance for the effect of the duration of the maturation period on surface bacterial growth during storage at −1.1° C. subsequent to smoking are given in Table III. Surface counts, as averaged over all maturation periods, increased at a relatively uniform rate during

TABLE III

EFFECT OF PERIOD OF MATURATION ON SURFACE BACTERIAL GROWTH ON SMOKED BACON DURING STORAGE AT −1.1° C.

Maturation period, days	Days from cure				Mean[2]
	29	55	97	139	
	Log_{10} of number of organisms per sq. cm. after storage[1]				
1	1.91	3.75	5.20	4.36	3.81
4.5	2.39	3.57	5.15	6.07	4.30
8	2.71	2.46	4.20	6.42	3.95
11.5	1.12	1.48	2.41	4.79	2.45
15	1.43	0.75	4.11	4.30	2.52
18.5	1.90	3.53	6.34	6.89	4.66
22	1.91	1.14	2.47	5.01	2.63
25.5	2.10	2.40	3.62	5.73	3.46
Mean[3]	1.94	2.39	4.19	5.39	—

Analysis of variance

Source of variance	D.f.	Mean square
Maturation period	7	11.618*
Error	24	3.610
Storage period	3	82.306**
Storage period × maturation period	21	2.296
Error	72	1.742

[1] *Mean values for four sides.*
[2] *Necessary difference, 5% level of statistical significance: 0.93.*
[3] *Necessary difference, 5% level of statistical significance: 0.66.*
* *Exceeds 5% level of statistical significance.*
** *Exceeds 1% level of statistical significance.*

storage, with differences in count between 55, 97, and 139 days reaching the level of statistical significance. Least growth occurred during storage on sides matured for 11.5, 15, and 22 days. While this behaviour may be a direct reflection of the maturation period only, the lack of systematic differences between the various periods suggests that it is more probably due to such causes as unknown variations in the smoking procedure, bacterial flora, or the initial, general condition of the sides.

Visual examination of the samples after the various storage periods indicated the presence of a slight amount of slime on four samples after 55 days, and a slight to heavy growth on five samples after 139 days. Some moulds were present at 97 and 139 days. There appeared to be no relation between maturation period and extent of slime and mould growth.

Fat Stability

The peroxide content of the fat of the samples of back bacon increased significantly during storage, with the greatest change occurring between 97 and 139 days (Table IV). The length of the maturation period was without

TABLE IV

EFFECT OF PERIOD OF MATURATION ON PEROXIDE OXYGEN FORMATION IN FAT OF SMOKED BACON DURING STORAGE AT −1.1° C.

Maturation period, days	Days from cure				Mean
	29	55	97	139	
	Peroxide oxygen content, ml. 0.002 *N* $Na_2S_2O_3$				
1	0.86	0.85	1.77	4.01	1.88
4.5	0.95	2.92	3.36	5.69	3.23
8	0.85	2.45	2.87	7.82	3.49
11.5	1.02	1.38	3.72	7.20	3.33
15	0.98	3.62	3.89	7.68	4.04
18.5	0.89	1.28	1.85	5.34	2.34
22	0.90	1.01	2.26	6.94	2.78
25.5	0.92	3.11	2.90	7.93	3.72
Mean	0.92	2.08	2.83	6.57	—

Analysis of variance

Source of variance	D.f.	Mean square
Maturation period	7	8.38
Error	24	4.86
Storage period	3	191.37**
Storage period × maturation period	21	2.30
Error	72	2.91

** *Exceeds 1% level of statistical significance.*

significant effect. It would appear that Wiltshire bacon can be held at −1.1° C. for periods as long as 25.5 days prior to smoking without harm to the keeping quality of fat during subsequent storage.

Colour and Colour Stability

Brightness, i.e. the total light scattered, of the freshly cut meat surface after smoking bore no significant relation to the length of the maturation period (Tables V and VI), but on the average decreased significantly during subsequent storage at −1.1° C. The maturation period had significant differential effect on brightness changes occurring during storage. The values for samples matured for 3.5 and 8 days were significantly the lowest after smoking and increased slightly on storage, whereas those for the other periods decreased. Brightness after smoking was greatest for the 25.5-day group but decreased the most during storage. It would appear that samples matured for 1 and 15 days had on the average the most satisfactory brightness.

Data on the relative amount of light scattered in the various wave bands studied are given also in Tables V and VI. Variations in the colour intensities with maturation period were somewhat irregular. However, in general, violet intensity was least for sides matured from 8 to 15 days and greatest for

TABLE V

EFFECT OF PERIOD OF MATURATION ON COLOUR CHANGES OF SMOKED BACON STORED AT −1.1° C.

Factor	Mean brightness[1]	Mean scatter[1]								
		3850–4340 Å	4340–4580 Å	4580–4870 Å	4870–5250 Å	5250–5560 Å	5560–5840 Å	5840–6140 Å	6140–6440 Å	Above 6440 Å
Maturation period, days										
1	28.7	45.7	120.6	124.3	175.8	112.5	176.8	103.3	69.7	71.6
4.5	27.2	46.2	123.5	122.9	174.1	112.5	172.7	103.9	70.8	73.9
8	23.7	44.9	123.0	121.7	173.8	111.3	171.8	104.2	73.1	77.1
11.5	26.1	39.4	121.3	122.7	175.6	114.7	176.5	105.3	70.4	74.3
15	28.5	43.6	121.5	123.8	174.1	115.0	178.3	102.9	69.9	70.8
18.5	26.6	47.1	120.3	123.4	176.2	111.8	176.2	103.1	70.3	71.7
22	27.9	49.5	120.5	123.3	174.4	111.7	176.2	102.5	69.7	72.3
25.5	29.4	47.9	123.9	123.1	174.9	113.4	176.3	101.2	68.8	70.4
Necessary difference[2]	—	4.4	—	—	—	—	3.9	—	—	—
Storage time										
After smoking	28.5	47.2	124.9	122.9	174.9	113.0	172.6	102.5	69.9	72.5
25.5 days after cure	26.6	46.7	120.2	122.1	173.8	111.8	175.1	104.6	72.0	73.7
30 days after smoking	26.7	42.8	120.4	124.4	175.9	113.8	179.1	102.8	69.1	72.1
Necessary difference[2]	0.9	2.7	1.3	1.5	1.5	1.2	2.4	1.1	1.5	—

[1] *Mean values for all other conditions over the whole experiment.*
[2] *Necessary difference required to exceed 5% level of statistical significance.*

TABLE VI

ANALYSES OF VARIANCE FOR THE EFFECT OF MATURATION PERIOD ON THE COLOUR CHANGES OF SMOKED BACON STORED AT −1.1° C.

Source of variance	D.f.	Total brightness	Mean square								
			3850–4340 Å	4340–4580 Å	4580–4870 Å	4870–5250 Å	5250–5560 Å	5560–5840 Å	5840–6140 Å	6140–6440 Å	Above 6440 Å
Maturation period	7	39.07	112.91**	25.43	13.00	9.57	22.57	58.57*	17.71	18.86	58.86
Error	24	33.98	30.37	36.29	11.58	22.08	15.58	31.88	22.21	35.21	70.58
Storage time	2	38.08**	185.14**	231.50**	45.50**	35.00*	34.00**	340.50**	41.00**	73.00**	24.00
Storage time × maturation period	14	27.63**	120.34**	12.86	15.50*	20.29*	25.36**	23.93	5.50	7.79	11.64
Error	48	3.29	29.16	6.94	6.94	9.42	5.54	19.13	5.13	8.35	10.81

* *Exceeds 5% level of statistical significance.*
** *Exceeds 1% level of statistical significance.*

22 days. Although differences in the blue region were small, sides matured for 22 and 25.5 days usually had higher intensity values. There was some indication that maturation periods of 4.5 and 8 days were associated with minimum green and maximum red intensities. During storage at −1.1° C. for 30 days after smoking, colour intensities on the average decreased in the

violet and blue, increased in the green, and showed little change in the red. Analyses of variance showed that the observed differences reached the level of statistical significance for maturation period in one band in each of the violet and green regions and for storage in all bands except that above 6440 Å. These primary factors also showed significant differential effects.

The results of the measurements on colour stability are given in Tables VII and VIII. Differences due to the length of the maturation period again

TABLE VII

EFFECT OF PERIOD OF MATURATION ON THE MEAN VALUES OF THE COLOUR STABILITY OF SMOKED BACON STORED AT −1.1° C.

Factor	Mean change in brightness[1]	Mean change in scatter[1]								
		3850–4340 Å	4340–4580 Å	4580–4870 Å	4870–5250 Å	5250–5560 Å	5560–5840 Å	5840–6140 Å	6140–6440 Å	Above 6440 Å
Maturation period, days										
1	−0.40	−0.17	−5.17	−0.17	+4.33	+6.17	+12.42	−5.25	−6.50	−5.00
4.5	+0.13	+0.92	−7.00	+0.33	+2.75	+2.92	+10.25	−3.33	−5.17	−3.50
8	−0.31	−0.67	−3.83	+3.67	+4.00	+2.67	+6.92	−2.08	−5.08	−5.58
11.5	−0.15	+3.17	−5.83	+1.08	+3.67	+2.67	+9.25	−4.25	−4.83	−3.92
15	−0.56	+2.75	−3.92	−0.42	+4.50	+1.08	+7.58	−2.08	−5.67	−3.17
18.5	−0.38	−1.67	−3.92	+2.58	+3.08	+4.33	+9.75	−3.08	−6.83	−4.58
22	−0.67	+0.33	−2.42	+1.33	+5.42	+3.58	+7.58	−3.75	−6.17	−6.17
25.5	−0.33	−0.50	−4.48	+1.50	+3.00	+1.42	+5.83	−1.41	−3.33	−2.42
Necessary difference[2]	—	—	—	—	—	—	3.40	2.10	—	0.70
Storage time										
After smoking	−0.58	−1.44	−4.94	+1.44	+4.81	+4.13	+11.13	−3.91	−6.44	−5.13
25.5 days after cure	−0.20	+0.09	−2.50	+1.59	+3.06	+2.72	+7.03	−3.50	−5.84	−3.53
30 days after smoking	−0.22	+2.91	−6.25	+0.41	+3.66	+2.47	+7.93	−2.06	−4.06	−4.22
Necessary difference[2]	—	—	2.00	—	—	—	2.10	1.30	1.40	—

[1] *Mean values for all other conditions over the whole experiment.*
[2] *Necessary difference required to exceed 5% level of statistical significance.*

TABLE VIII

ANALYSES OF VARIANCE FOR THE EFFECT OF MATURATION PERIOD ON THE COLOUR STABILITY OF SMOKED BACON STORED AT −1.1° C.

Source of variance	D.f.	Mean square									
		Total brightness	3850–4340 Å	4340–4580 Å	4580–4870 Å	4870–5250 Å	5250–5560 Å	5560–5840 Å	5840–6140 Å	6140–6440 Å	Above 6440 Å
Maturation period	7	0.72	0.58	23.85	22.87	9.71	31.71	54.00**	19.43**	14.83	19.40*
Error	24	0.59	51.98	16.64	8.36	7.38	15.08	18.92	5.50	9.47	7.36
Storage time	2	1.53	38.14	115.88**	18.20	25.50	25.50	148.00**	30.00*	48.89**	20.40
Storage time × maturation period	14	0.49	214.09**	24.32	13.27	19.71*	19.79*	47.64**	13.21*	19.92**	11.87
Error	48	0.52	47.14	15.40	16.59	10.19	8.06	15.94	7.13	7.46	7.96

* *Exceeds 5% level of statistical significance.*
** *Exceeds 1% level of statistical significance.*

TABLE IX

EFFECT OF PERIOD OF MATURATION ON THE FLAVOUR OF SMOKED WILTSHIRE BACKS AND GAMMONS

Material	Periods compared, days	Total flavour score[1]							
		Days							
		1	4.5	8	11.5	15	18.5	22	25.5
Backs	1 and 4.5	+0.56 (1)	−0.56 (2)	—	—	—	—	—	—
	1 to 8	+0.85 (1)	+0.43 (2)	−1.28 (3)	—	—	—	—	—
	1 to 11.5	−2.13 (3)	−4.25 (4)	+1.28 (2)	+5.10 (1)	—	—	—	—
	1 to 15	+0.43 (2)	−1.70 (4)	0.00 (3)	+3.83 (1)	−2.55 (5)	—	—	—
	1 to 18.5	0.00 (4)	−1.28 (5)	+2.98 (1)	+1.28 (2)	−3.83 (6)	+0.85 (3)	—	—
	1 to 22	−2.13 (5)	+0.85 (3)	−0.43 (4)	−5.10 (6)	+4.25 (1)	+2.98 (2)	−0.43 (4)	—
	1 to 25.5—								
	Trial I	−2.79 (7)	−0.90 (5)	−2.75 (6)	+5.39 (1)	+0.04 (4)	+3.35 (2)	+1.07 (3)	−3.41 (8)
	Trial II	−0.04 (4)	−6.26 (8)	−2.10 (6)	−0.28 (5)	−4.12 (7)	+4.59 (1)	+3.77 (3)	+4.44 (2)
	Trial III	+0.62 (3)	−4.68 (8)	−1.10 (5)	+0.43 (4)	−2.15 (6)	+6.87 (1)	−2.25 (7)	+2.25 (2)
Gammons	1 and 4.5	+2.24 (1)	−2.24 (2)	—	—	—	—	—	—
	1 to 8	+1.70 (1)	−1.70 (3)	0.00 (2)	—	—	—	—	—
	1 to 11.5	−0.85 (3)	−2.55 (4)	+3.83 (1)	−0.43 (2)	—	—	—	—
	1 to 15	+0.85 (2)	−2.13 (5)	−0.43 (4)	0.00 (3)	+1.70 (1)	—	—	—
	1 to 18.5	+0.85 (2)	0.00 (3)	−2.98 (5)	−0.85 (4)	+2.98 (1)	0.00 (3)	—	—
	1 to 22	+2.13 (3)	−0.43 (4)	+2.55 (2)	−2.55 (5)	+6.38 (1)	−3.40 (6)	−4.68 (7)	—
	1 to 25.5—								
	Trial I	+5.71 (1)	+4.27 (2)	+2.04 (4)	+0.50 (6)	+3.39 (3)	+0.97 (5)	−4.63 (7)	−12.23 (8)
	Trial II	+2.88 (1)	−0.02 (5)	−0.45 (6)	−2.90 (7)	+0.90 (4)	+2.30 (2)	−4.40 (8)	+1.70 (3)
	Trial III	+3.63 (2)	−0.07 (4)	−2.66 (7)	+1.40 (3)	−0.64 (5)	+3.78 (1)	−3.78 (8)	−1.65 (6)

[1] *Figures in parentheses indicate the order of preference within any one set of comparisons.*

showed no definite trend. Brightness stability appeared to be best for the 4.5-day period and poorest for 22 days, but the differences were not significant. There was some indication that sides matured from 1 to 11.5 days had on the average greater negative values in the blue and greater positive values in green than those held for longer periods prior to smoking. A similar comparison for changes in red intensity shows that the values are negative and of approximately the same average magnitude.

During storage at −1.1° C. for 30 days after smoking, the stability values, as averaged over all maturation periods became less negative or more positive in brightness and the violet and red bands; and more negative or less positive in the blue and green bands. Certain of these changes were statistically significant.

Flavour

Mean values and analyses of variance for the flavour scores of both backs and gammons are given in Tables IX and X. No distinct relation was evident between the length of the maturation period and flavour quality of either the

TABLE X

ANALYSES OF VARIANCE FOR THE EFFECT OF PERIOD OF MATURATION ON THE FLAVOUR OF SMOKED WILTSHIRE BACKS AND GAMMONS

Periods compared, days	Source of variance	D.f.	Mean square	
			Backs	Gammons
1 and 4.5	Maturation period	1	0.052	0.836
	Error	11	0.508	0.494
1 to 8	Maturation period	2	0.105	0.241
	Error	22	0.499	0.701
1 to 11.5	Maturation period	3	1.569	0.689
	Error	29	0.548	0.689
1 to 15	Maturation period	4	0.605	0.208
	Error	36	0.605	0.710
1 to 18.5	Maturation period	5	0.610	0.426
	Error	35	0.491	0.517
1 to 22	Maturation period	6	1.045	1.638*
	Error	50	0.583	0.540
1 to 25.5, Trial I	Maturation period	7	0.823	2.841**
	Error	77	0.646	0.527
1 to 25.5, Trial II	Maturation period	7	1.376*	0.537
	Error	77	0.631	0.697
1 to 25.5, Trial III	Maturation period	7	1.018	0.641
	Error	77	0.638	0.722

* *Exceeds 5% level of statistical significance.*
** *Exceeds 1% level of statistical signifiacnce.*

TABLE XI

MEAN VALUES AND ANALYSES OF VARIANCE FOR THE CONTENTS OF CURING SALTS AND OF MOISTURE IN SMOKED WILTSHIRE BACKS AND GAMMONS MATURED FOR VARIOUS PERIODS

Maturation period, days	Sodium chloride[1], %		Sodium nitrate[1], %		Sodium nitrite[1], p.p.m.		Moisture[1], %	
	Back	Gammon	Back	Gammon	Back	Gammon	Back	Gammon
1	6.54	5.15	0.20	0.28	576	179	64.6	70.0
4.5	6.04	5.43	0.24	0.28	175	125	60.4	67.2
8	7.67	5.47	0.15	0.36	42	108	61.5	68.2
11.5	6.60	4.66	0.30	0.22	21	99	60.0	70.2
15	5.87	5.66	0.19	0.33	10	98	59.5	68.5
18.5	6.39	4.92	0.17	0.33	47	45	64.8	69.5
22	7.08	5.67	0.32	0.30	5	24	61.2	69.5
25.5	7.54	5.91	0.25	0.35	14	43	62.2	68.7

Analyses of variance

Constituent	Source of variance	D.f.	Mean square	
			Backs	Gammons
Sodium chloride	Maturation period	7	0.889	0.351
	Error	8	0.645	0.465
Sodium nitrate	Maturation period	7	0.007	0.004
	Error	8	0.017	0.008
Sodium nitrite[2]	Maturation period	7	0.831*	0.161
	Error	8	0.204	0.100
Moisture	Maturation period	7	8.068	2.095
	Error	8	6.651	3.053

[1] *Mean values for two sides.*

[2] *Values transformed to logarithms prior to statistical analysis.*

* *Exceeds 5% level of statistical significance.*

backs or gammons. However, there was some indication that the flavour of the backs was preferable after they were matured for 11.5 or 18.5 days, and that of the gammons, after 1 or 15 days. Thus, it would appear that the most suitable period for the development of the desired flavour in whole Wiltshire sides is about 15 days. However, it should be noted that the observed differences for the most part were not statistically significant.

To determine whether observed differences in palatability were due to variations in the content of curing salts, the concentration of sodium chloride, nitrate, nitrite, and of moisture were determined at the conclusion of the flavour tests for two backs and two gammons selected at random from those available for each maturation period. The methods employed have been described previously (5). The sodium chloride content (Table XI) was

somewhat higher and that of moisture lower than had been observed previously for Canadian Wiltshire bacon (12). Unavoidable desiccation during storage may have been partially responsible for this. Differences in the moisture and salt content between sides matured for various periods were not statistically significant. This suggests that any preferences indicated in flavour quality were due to other causes than the concentration of the above constituents.

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CANADIAN LINSEED

I. THE EFFECT OF VARIETY AND ENVIRONMENT ON THE COMPOSITION OF LINSEED[1]

By H. R. Sallans[2]

Abstract

Data for oil content, nitrogen, iodine value, 1000-kernel weight, and refractive indices of extracted and expressed oil were determined on three varieties of flax, i.e., Bison, Royal, and Redwing, grown at 35 stations in Saskatchewan. Varietal differences were demonstrated for all properties with the exception of total nitrogen, and significant differences were obtained for all properties due to the effect of environment.

Within varieties, highly significant simple correlation coefficients were obtained between iodine value (Hanus) and refractive indices of both expressed and extracted oils. Analysis of residual variance showed that varietal regressions did not differ significantly and prediction equations applicable with equal validity to all three varieties could be derived. Partial correlation coefficients, independent of nitrogen, indicate that these associations are independent of the latter property. A significant association ($r = .497^{**}$) between oil content and 1000-kernel weight proved to be due to common association of these properties with total nitrogen.

A simple intravarietal correlation coefficient of $r = -.817^{**}$ was obtained between nitrogen and oil content. Analysis of residual variance indicated that varietal regressions did not differ in slope and that on the average an increase of 1% in nitrogen was associated with a decrease of 2.45% in oil content. Oil content may be estimated with a standard error of $\pm$ 0.57% from the equation, oil content $= -2.54$ nitrogen $+ A$, where A is a varietal constant.

** *Indicates that the 1% level of significance was attained.*

Disruption of trade and shipping facilities, caused by the war, has placed Canada in an unfavourable position with respect to supplies of vegetable oils. The only vegetable oil crop produced in Canada has been flax and in a recent publication Lehberg and Anderson (7) indicated that in the period preceding the war, production had fallen well below domestic requirements. Since high quality flax can be produced in Canada (1), and facilities and seed stocks were available, a marked expansion in linseed production was stimulated. It appears that, in addition to supplying a greatly expanded demand for its normal uses in paints, varnishes, linoleum, and printers' inks, linseed oil will have to be processed to supply substitutes for certain drying oils and other oil products not now available. The extent to which this substitution can be carried will depend on necessity and technical skill in processing the oil. However, it is obvious that a knowledge of the composition of linseed oil, and the manner in which it varies with variety and environment, is of fundamental importance in adapting this oil for use in replacing oils that were previously imported.

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[2] *Biochemist, Oil Seeds Laboratory, University of Saskatchewan.*

The effects of variety and environment on the composition and quality of Canadian wheat (10) and barley (10) have been intensively studied, but flax has been regarded as a minor crop and no comprehensive study on Canadian flax has appeared in the literature. Most of the published data (1, and previous reports, 10) have taken little cognizance of the effect of variety on composition. However, studies made in connection with flax breeding (9) have shown varietal differences, and the results of annual crop surveys (1) have served to show the effect of environment on commercial samples. It therefore appears desirable to record data on the effects of environment on the composition of the three principal flax varieties being produced in Western Canada. While the present paper is confined to the usual determinations of oil content, iodine value, nitrogen, and refractive index and their interrelations, it is proposed to extend this study to more fundamental relations in subsequent papers.

Materials and Methods

The samples selected for this study were obtained through the Saskatchewan Co-operative Wheat Producers and complete data regarding the design of the test, yield per acre, days to maturity, plant height, weight per bushel, and commercial grades of the samples are available in a published bulletin (11). Briefly, the material consisted of the varieties Bison, Royal, and Redwing grown in test plots at 35 stations in Saskatchewan. The location of the stations is shown in Fig. 1 and the key to stations is listed in the first column of Table II. At each station six replicate plots of each variety were grown in a modified Latin square and the individual plot yields were composited by varieties.

TABLE I

VARIETAL MEANS FOR FLAX PROPERTIES

Variety	Yield, bu. per acre	Total nitrogen, % dry basis	Nitrogen, % in oil free meal	1000-Kernel wt., gm. dry basis	Refractive index, extracted oil	Oil content, % dry basis	Iodine value, Hanus
Bison	12.20	4.49	7.67	5.62	1.47892	41.50	178.82
Royal	13.29	4.50	7.62	5.11	1.47883	41.00	177.91
Redwing	12.97	4.48	7.43	4.42	1.47978	39.70	186.01
Necessary diff., 5% level	1.10	0.04	0.07	0.09	0.00012	0.22	1.08

Cleaning

Before the samples were submitted to analysis, they were put through a Perkins flax dockage tester with a maximum flow of air. This procedure removed approximately 5% of the samples. Most of the material removed consisted of broken flax together with a few thin and immature kernels. The samples were then randomized and analysed in duplicate.

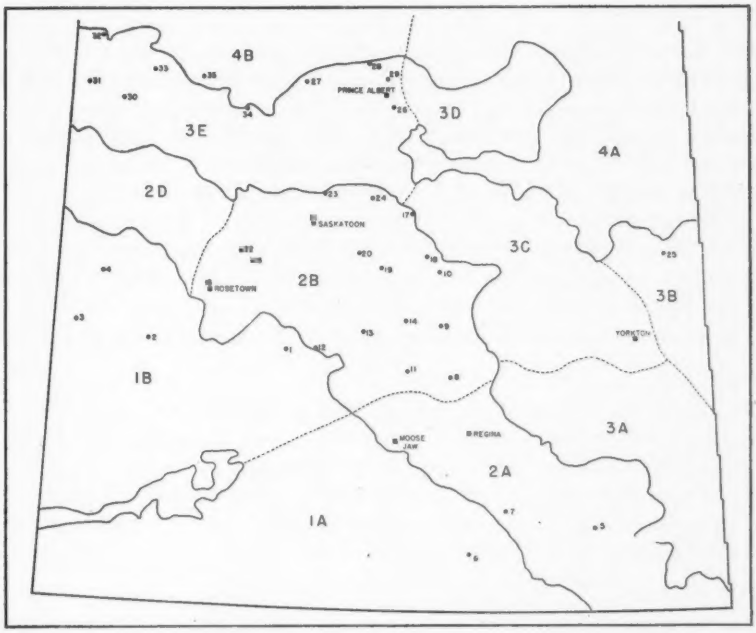

FIG. 1. *Map of Saskatchewan showing cereal variety zones and stations from which samples were received. The key for stations is given in the first column of Table II.*

Moisture

After some preliminary tests on ground samples, it was decided to determine moisture on whole kernels. This was found to yield more concordant results between duplicates and gave less trouble in maintaining constant weight on moisture dishes than when ground seed was used. Two-gram samples were weighed into aluminum moisture dishes and dried at 100° C. in a vacuum oven for 18 hr. The samples showed a range of less than 0.5% in moisture and the standard error of the mean of duplicate determinations was found to be $\pm$ 0.035%.

Nitrogen

Nitrogen was determined in duplicate on 1-gm. samples of whole kernels by the Kjeldahl method. The standard error of the mean of duplicates proved to be $\pm$ 0.028%.

1000-Kernel Weight

Duplicate aliquots of 200 kernels were counted and weighed. In this operation, chipped and broken kernels were discarded. Weights usually agreed within 1% and, in calculating 1000-kernel weight, the weight of 400 kernels was multiplied by the factor 2.5 and converted to dry basis.

Oil Content

For the determination of oil content, a 25-gm. sample was ground in an Allis Chalmers experimental roller mill that had 40 corrugations per inch and a differential roll speed of 2 to 1 (2). After mixing thoroughly, a 4-gm. aliquot was weighed, wrapped in two Whatman No. 2 filter papers and extracted for 18 hr. with petroleum ether (Skellysolve *F.*) in a Goldfisch extraction apparatus. The oil was subsequently dried for 1 hr. at 100° C. in a vacuum oven. Tests of extraction time showed 37.81% oil after 5.5 hr. and 38.23% oil after 16 hr., for the mean of six determinations on the same flax sample. Further extraction, even after grinding the samples with sand, gave no significant increase in oil content.

The means of duplicate determinations showed a standard error of $\pm 0.14\%$.

Refractive Index

Refractive indices were determined with a Bausch and Lomb Precision laboratory refractometer at 25° C. $\pm$ 0.05°. Determinations were made on oil samples, cold-pressed according to the procedure of Geddes and Lehberg (8), and also on the oil residues obtained in the determination of oil content. The standard error of the means of duplicates was $\pm$ .000035 units in refractive index.

Iodine Values

Iodine numbers were determined by the Hanus method with a 30 min. reaction time. The standard error of the mean of duplicates was $\pm$ 0.30 units.

Nitrogen Content of Oil Free Meal

It is the practice of the Board of Grain Commissioners' Laboratory to report the protein content of the oil free meal in their annual reports on the quality of the Western Canadian flax crop (1). The nitrogen content of the oil free meal has, therefore, been calculated from data on oil and nitrogen contents to compare the relations between these values and other flax properties with similar relations involving total nitrogen.

Differences Between Varieties and Between Stations

The data obtained for yield, total nitrogen, nitrogen in oil free meal, 1000-kernel weight, refractive index of extracted oils, oil content, and iodine value are summarized in Table I as means for each variety, over all stations, and in Table II as means for each station, over all varieties. Data for refractive indices of cold-pressed oils are not included in these tables, since these values were practically identical with those obtained on the extracted oils.

Owing to the differential effect of environment on varieties, these varieties did not fall in the same relative order at all stations, nor did the stations fall in the same order with respect to each variety. Analyses of variance were required to determine whether the observed differences between varietal and station means could be regarded as significant. The results of these anal-

TABLE II

STATION MEANS FOR FLAX PROPERTIES

Station	Yield, bu. per acre	Total nitrogen, % dry basis	Nitrogen, % in oil free meal	1000-Kernel wt., gm. dry basis	Refractive index, extracted oil	Oil content, % dry basis	Iodine value, Hanus
1. Birsay	3.0	4.87	8.07	4.62	1.47877	39.6	177.9
2. Eston	4.7	4.14	7.06	4.70	1.47904	41.3	180.7
3. Mantario	14.3	4.51	7.48	4.80	1.47866	39.7	177.2
4. Driver	14.3	4.27	7.35	4.83	1.47938	41.8	182.8
5. Stoughton	8.1	4.92	8.20	4.78	1.47890	40.0	178.7
6. Ceylon	18.3	4.30	7.44	5.06	1.47913	42.1	180.4
7. Yellow Grass	8.7	4.63	7.78	4.78	1.47913	40.4	180.2
8. Gibbs	11.0	4.74	7.97	5.08	1.47929	40.5	182.4
9. Govan	27.7	4.48	7.59	5.72	1.47927	41.0	181.1
10. Drake	9.0	4.47	7.57	5.02	1.47910	41.0	180.5
11. Holdfast	8.3	4.79	8.02	5.19	1.47925	40.3	181.3
12. Elbow	6.7	4.84	8.06	4.94	1.47940	40.0	182.6
13. Davidson	8.7	4.51	7.70	5.21	1.47924	41.5	180.6
14. Imperial	6.3	4.66	7.69	4.79	1.47922	39.4	181.2
15. Tessier	10.3	4.39	7.44	5.19	1.47877	41.0	176.6
16. Rosetown	9.0	4.34	7.41	5.31	1.47940	41.4	183.1
17. Carmel	17.0	4.41	7.48	5.09	1.47895	41.1	178.6
18. Guernsey	16.0	4.38	7.48	5.07	1.47954	41.5	183.7
19. Young	15.3	4.10	7.06	5.66	1.47932	42.0	181.5
20. Allen	10.0	4.47	7.53	5.03	1.47909	40.6	180.4
21. Saskatoon	30.7	4.32	7.33	5.34	1.47912	41.1	180.0
22. Feudal	21.7	4.21	7.22	5.55	1.47952	41.7	183.5
23. Osler	8.7	4.71	7.84	4.87	1.47877	39.9	177.5
24. Prud'homme	14.7	4.47	7.51	4.88	1.47869	39.5	177.4
25. Norquay	13.7	4.34	7.39	5.28	1.47918	41.3	181.4
26. Davis	8.3	4.69	7.85	4.56	1.47846	40.2	182.9
27. Mont Nebo	22.0	4.52	7.53	5.22	1.47894	40.0	179.5
28. Sturgeon Valley	16.7	3.67	6.39	5.16	1.47958	42.5	183.8
29. White Star	19.7	4.69	7.82	5.12	1.47914	40.1	181.5
30. Maidstone	7.7	4.70	7.87	5.03	1.47948	40.3	183.6
31. Marshall	10.0	4.54	7.59	4.84	1.47951	40.2	183.6
32. Frenchman Butte	5.0	4.69	7.90	4.77	1.47958	40.7	184.6
33. Mervin	18.3	4.48	7.45	5.12	1.47905	39.9	179.9
34. Mullingar	13.7	4.66	7.77	5.03	1.47883	40.1	177.4
35. Robinhood	10.7	4.20	7.12	5.05	1.47945	41.0	182.7
Mean all stations	12.8	4.49	7.57	5.05	1.47918	40.7	180.9
Range	27.7	1.25	1.81	1.16	0.00089	3.1	8.0
Necessary difference, 5% level	3.7	0.14	0.22	0.31	0.00041	0.76	3.7

yses are shown in Table III and the necessary differences between means for the 5% level of significance, i.e., for odds of 19 to 1 that a real difference exists between the means, are given in the last lines of Tables I and II.

A comparison of the necessary difference for significance with the observed differences between varietal means in Table I indicates that real differences exist among the varieties in 1000-kernel weight, refractive index, oil content, iodine value, and nitrogen in the oil free meal. The differences in total nitrogen are not significant, while the difference between Bison and Royal in yield per acre closely approach a significant value. The fact that the varieties

TABLE III

ANALYSES OF VARIANCE FOR FLAX PROPERTIES: MEAN SQUARES

Flax property	Varieties	Variance due to:	
		Stations	Interaction
Yield per acre	10.9238	120.5557**	5.2473
Total nitrogen, %	0.002160	0.193493**	0.007738
Nitrogen, % in oil free meal	0.54782**[1]	0.37844**	0.01902
1000-Kernel wt., gm.	12.76149**	0.21706**	0.03525
Refractive index, extracted oil	95,461.05**	2197.13**	643.51
Refractive index, expressed oil	100,602.10**	2209.30**	684.80
Oil content, % dry basis	29.4980**	1.8004**	0.2208
Iodine value, Hanus	689.731**	14.532**	5.144
Degrees of freedom	2	34	68

[1] *Throughout the text and in Tables III and V to VII, ** indicates that the 1% level of significance has been attained.*

do not differ in total nitrogen while Redwing is significantly lower than either Bison or Royal, in nitrogen content in the oil free meal, results from a lower value for Redwing in oil content. Since Redwing is definitely lower in 1000-kernel weight than the other varieties, it appears that its ratio of hull to endosperm would be larger. This suggests that meal from Redwing flax contains a greater percentage of hull and, consequently, a higher percentage of structural material such as fibre and lignin that may detract slightly from its value as a stock feed.

It is evident from the data in Table II that changes in environment produce highly significant differences in all the properties listed. As would be expected, yield per acre shows the widest variation while the values for chemical composition are relatively much more uniform. From a quality viewpoint, it is interesting to note that the range in values for iodine value, 1000-kernel weight, and refractive index for station means are approximately the same as those for varietal means. This would indicate that, in the case of iodine values, a sample of Redwing flax from an area producing the lowest iodine values would be approximately equal in this property to a sample of Bison or Royal from an area producing the highest average iodine values.

To illustrate the effect of environment more clearly, means for cereal variety zones are shown in Table IV. From the practical viewpoint of the flax producer, under our present grading system, yield per acre is the most important single factor. It will be noted that the highest average yields were obtained in Zone 2*B*, whose yields are closely followed by those of Zone 3*E*. These results are in agreement with data reported by Lehberg and Anderson (7) and explain why flax production has tended to concentrate in the central and west central portions of Saskatchewan. However, the data for Zone 3*E* suggest that more flax might well be grown profitably in the more northerly

TABLE IV

MEANS FOR FLAX PROPERTIES BY CEREAL VARIETY ZONES

Zone	No. of stations	Yield, bu. per acre	Total nitrogen, % dry basis	Nitrogen, % in oil free meal	1000-Kernel wt., gm. dry basis	Refractive index, extracted oil	Oil content, % dry basis	Iodine value, Hanus
1*B*	4	9.07	4.45	7.49	4.74	1.47896	40.6	179.6
2*A*	3	11.70	4.62	7.81	4.87	1.47905	40.8	179.8
2*B*	17	13.59	4.49	7.58	5.17	1.47917	40.8	180.7
3*E*	9	13.49	4.52	7.57	4.98	1.47918	40.4	181.9

areas. This should not appreciably affect the quality of the flax produced, though the data do suggest that a slight lowering of oil content and an increase in iodine value might occur on the assumption that varieties were uniformly distributed. However, detailed data on yields (11) indicate that this would not be the case. In Zones 2*A* and 2*B* it was shown that Royal exceeded both Bison and Redwing by 2.3 bushels per acre, while in Zones 3*D* and 3*E* Redwing exceeded both Bison and Royal by 2.0 bushels per acre. It is thus evident that a considerable interaction between variety and environment exists with respect to yield, and that in northerly areas Redwing will be grown in preference to other varieties. This will result in flax of comparatively low oil content and high iodine value from this area. From a study of survey maps (1), it appears that this tendency is already evident and if flax production is extended northward will become increasingly important.

The question of oil quality has received scant attention with respect to Western Canadian flaxseed. In general, specifications for raw linseed oil usually specify an iodine value of not less than 175 to 177 units (6). The annual surveys of Western Canadian flax crops (1) indicate that even in years of low iodine value a very small proportion of the total crop, probably only about 5%, will fail to attain this value. An oil crusher using Western Canadian flaxseed may, therefore, be almost certain that his product will meet minimum specifications for this quality. Consequently, his chief concern is oil yield and he would normally prefer to crush Bison in preference to either Royal or Redwing. If flax production is pushed farther north with a consequent increase in the amount of Redwing flax, there will be a tendency to lower average oil yield and, since no premium is being paid for high iodine values, the crop as a whole will be less attractive to the crushing industry. It therefore appears that intensive efforts should be undertaken to develop an early maturing flax variety, adapted to northern areas, that produces a better yield of oil than Redwing, and that a study of the importance of iodine value of linseed oil in relation to its commercial utilization should be made. If it can be conclusively demonstrated that high iodine values in linseed oil are worthy of a premium, it should enhance the value of the total crop and make the production of a variety such as Redwing attractive in spite of its lower oil yield.

Relations Between Flax Properties

Since only three varieties were investigated no adequate study of relations between varieties can be made and the discussion in this section will, therefore, be confined to the manner in which the composition of the varieties responds to changes in environment.

Simple intravarietal correlations between station means were computed and appear in Table V. Comparison of the coefficients for total nitrogen, with those for nitrogen content of the oil free meal, indicate that the relations between these properties and the remaining ones are very similar, since the coefficients are similar in both magnitude and sign. The only difference is that the coefficients for nitrogen in the oil free meal are consistently slightly lower than those for total nitrogen and, since these two properties are very closely related (r = .9869**), it is evident that only the relations of total nitrogen with other characteristics need be considered.

TABLE V

SIMPLE INTRAVARIETAL CORRELATION COEFFICIENTS BETWEEN FLAX PROPERTIES

Flax property	Nitrogen, % dry basis	Nitrogen, % in oil free meal	1000-Kernel wt., gm.	Oil content, % dry basis	Iodine value, Hanus	n_D, extracted oil	n_D, expressed oil
Yield, bu. per acre	−.4024[1]	−.3920*	.6629**	.3201	−.0257	−.0130	−.0061
Nitrogen, %		.9869**	−.4282**	−.8167**	−.2371	−.2742	−.2798
Nitrogen, % in oil free meal			−.3809*	−.7134**	−.1843	−.2147	−.2148
1000-Kernel wt., gm.				.4974**	.1571	.2063	.2042
Oil content, % dry basis					.3785*	.4309**	.4454**
Iodine value, Hanus						.9779**	.9800**
n_D, extracted oil							.9971**

[1] *Throughout the text and in Tables V and VI,* indicates that the 5% level of significance has been attained.*

For any given variety, it appears that as nitrogen content decreases there is a significant tendency for yield, 1000-kernel weight, and total oil content to increase. While the relations between nitrogen content on one hand and iodine value and refractive indices on the other are not significant, they are all negative, indicating a possible tendency to higher iodine values with decrease in nitrogen. These observations confirm the conclusion that high quality flaxseed can be produced in areas that produce wheat of low nitrogen content.

The relatively high correlation coefficient (r = .6629**), within a variety, for yield and 1000-kernel weight, might suggest that differences in yield in flax can be accounted for largely by increases in seed size. Reference to the values in Table II shows a range of 1.16 units (23% of the mean value) in 1000-kernel weight, while the range in yield is 27.7 units (216% of the mean value). It is thus evident that other factors besides 1000-kernel weight

influence yield, and it appears that growing conditions favouring a good stand of flax also favour the development of large kernels. The tendency for larger kernels to yield a higher percentage of oil ($r = .4974^{*}$) has been noted by previous workers. It is obvious that even when a single variety is considered, the relation is not sufficiently close to make 1000-kernel weight a practical index of oil content. The value ($r = .444^{**}$) obtained by Geddes and Lehberg (3) for commercial samples is comparable to the above value and suggests that this relation may be relatively independent of variety.

An interesting feature of the data is that significant positive correlations were obtained between oil content and the properties, iodine value and refractive index. This would indicate a tendency for high oil content to be associated with a high degree of unsaturation. The degree of association is not particularly close; but in view of the definite tendency for varieties high in oil content to be low in iodine value (9), this result is of definite significance. Thus, while the selection of a variety high in oil content shows a definite tendency to produce a low quality oil, the production of any given variety in a high oil yielding area shows no tendency to yield oil of lower quality; on the contrary, the chances are that an oil of superior quality will be obtained. There is a differential effect of environment on this relation that will be noted by reference to Fig. 1 and Table IV. For example, as one proceeds northward it will be noted that oil content shows a tendency to increase to a maximum and then decrease, while on the other hand iodine value shows a tendency to increase in a continuous manner. This effect is most marked in passing from Zone 2*B* to Zone 3*E*.

The high correlation coefficients among the properties, iodine value and refractive index of expressed and extracted oils is to be expected in view of previous work on the estimation of iodine values from refractive indices (4, 8).

To determine the effect of common associations of the properties with total nitrogen, partial correlation coefficients independent of total nitrogen were computed and these are shown in Table VI. The high value ($r = .9946^{**}$) for the coefficient between nitrogen content of oil free meal and oil content is

TABLE VI

INTRAVARIETAL PARTIAL CORRELATION COEFFICIENTS BETWEEN FLAX PROPERTIES, INDEPENDENT OF TOTAL NITROGEN

Flax property	Nitrogen, % in oil free meal	1000-Kernel wt., gm.	Oil content, % dry basis	Iodine value, Hanus	n_D, extracted oil	n_D, expressed oil
Yield, bu. per acre	.0349	.5931**	−.0162	.0693	.1106	.1212
Nitrogen, % in oil free meal		.2859	.9946**	.3171	−.0181	−.0184
1000-Kernel wt., gm.			.2832	.2946	.2221	.2254
Oil content, % dry basis				.3298	.3730*	.3915*
Iodine value, Hanus					.9772**	.9797**
n_D, extracted oil						.9992**

readily explained by the method of calculating the former values and the close intravarietal relation between total nitrogen and oil content. Relations between 1000-kernel weight and oil content are due largely to common associations of these properties with total nitrogen. The remainder of the partial correlation coefficients show no significant differences from the simple coefficients and it may be assumed that these relations are relatively independent of nitrogen content.

Regression Studies

In the preceding section the only relations that are sufficiently close to suggest that useful predictions might be developed are those between nitrogen and oil content and those among iodine value, refractive index of extracted oil and refractive index of expressed oil. The association between iodine value and refractive index has been investigated previously and equations for the prediction of iodine value have been developed. It appears that this relation is well established, since it can also be applied to soya-bean oil. However, the data obtained in the present study are such that a comparison can be made of:—varietal regressions for this relation and the use of cold-pressed or solvent extracted oils for the determination of refractive index. In addition iodine values were determined by the Hanus method instead of the usual Wijs procedure.

The third column in Table VII shows the analysis of residual variance for varietal regression of refractive index of solvent extracted oils on refractive index of cold-pressed oils. From the equation, n_D (solvent) = .98 n_D (pressed) + 0.000028, it was found that refractive index of extracted oils could be estimated with a standard error of $\pm$ 0.000032 units from values obtained on cold-pressed oils. This compares favourably with the standard error of duplicates, $\pm$ 0.000035, for refractive index measurements. In the fourth and fifth columns of Table VII, analyses of residual variance for varietal regression of iodine values on refractive indices of expressed and extracted

TABLE VII

TEST OF HOMOGENEITY OF VARIETAL REGRESSION COEFFICIENTS BY ANALYSES OF RESIDUAL VARIANCE

Variance due to:	Degrees of freedom	Mean square			
		n_D, extracted oil on n_D, expressed oil	Iodine value on n_D, expressed oil	Iodine value on n_D, extracted oil	Oil content on total nitrogen
Differences among varietal regression coefficients	2	11.325	0.08198	0.15130	0.290045
Deviations of varietal means from average regression	2	9.426	0.39224	0.32145	30.185450**
Residual deviations from individual regressions	99	10.2699	0.39283	0.44358	0.331664
Deviations from average varietal regression	103	10.0784	0.38679	0.43553	0.910542

oils are given. Since these analyses show that varietal regressions do not differ significantly and that varietal means do not deviate significantly from the average regression, it is obvious that the relations are homogeneous with respect to varieties. Thus, equations developed for the prediction of iodine values from refractive indices will be equally valid for the three varieties. These equations were determined and are:

(I). $I.V. = 8223.45\ N.p. - 11{,}982.99$ ($S.e. = \pm 0.62$)

(II). $I.V. = 8391.35\ N.e. - 12{,}231.40$ ($S.e. = \pm 0.66$)

where $I.V.$ = iodine value Hanus, $N.p. = n_D^{25}$ of cold-pressed oil and $N.e. = n_D^{25}$ of extracted oils. A combined analyses of variance for both sets of data indicated that the varietal regressions did not differ significantly, and reference to Table VII shows that the residual variance for differences among regression coefficients in each of the relations fails to attain significance. Hence, it may be concluded that the differences between Equations I and II are not significant and that iodine value can be estimated either from cold-pressed oil or from residues obtained in the oil determination when petroleum ether is used as a solvent. For comparative purposes, equations developed by other workers are listed below. Zeleny and Coleman (12) and Hopper and Nesbitt (5) using the Wijs method with one hour reaction time obtained Equations III ($I.V. = 8584.97\ n_D^{25} - 12{,}513.83$) and IV ($I.V. = 8441.67\ n_D^{25} - 12{,}301.45$), respectively, while Lehberg and Geddes (8) using the Wijs procedure with a one-half hour reaction time obtained the expression (V), $I.V. = 8028.45\ n_D^{25} - 11{,}690.71$. Comparing these equations at different values of refractive index, we obtain the data shown in Table VIII. The mean iodine value obtained by the Wijs method is 102.6% of that by the Hanus method at a refractive index of 1.4760 and 102.1% at 1.4810. This

TABLE VIII

COMPARISON OF DATA OBTAINED FROM FIVE EQUATIONS FOR PREDICTION OF IODINE VALUES FROM REFRACTIVE INDEX

Refractive index n_D^{25}	Hanus, iodine value			Wijs, iodine value			
	Equation I	Equation II	Mean	Equation III	Equation IV	Equation V	Mean
1.4760	154.8	154.2	154.5	157.6	158.4	159.4	158.5
1.4770	163.0	162.6	162.8	166.2	166.9	167.3	166.8
1.4780	171.3	171.0	171.2	174.8	175.3	175.2	175.1
1.4790	179.5	179.4	179.5	183.3	183.8	183.1	183.4
1.4800	187.7	187.8	187.8	191.9	192.2	191.2	191.8
1.4810	195.9	196.2	196.0	200.5	200.7	199.5	200.2
Standard error of estimate	±0.62	±0.66		±0.8	±1.5	±2.1	

variation is comparable to the differences obtained by using different equations and, consequently, it appears that an average factor of 1.023 will serve to estimate Wijs iodine values from Hanus values with a fair degree of accuracy.

Data on annual surveys of Western Canadian flaxseed (1, and previous reports) have shown no very close relation between oil content and nitrogen in the oil free meal. Since these data were obtained on commercial samples containing a mixture of varieties, it is of interest to determine the effects of variety on this relation. The final column in Table VII presents an analysis of residual variance for varietal regression of oil content on total nitrogen. The varietal regressions do not differ significantly, but the varietal means show highly significant deviations from the average varietal regression. Thus, while the varieties show a uniform decrease of 2.45% in oil content for each increment of 1% in nitrogen, it is impossible to represent the relation accurately by a single regression equation. A series of equations of the type,

$$\text{Oil content, \%} = -2.45 \text{ nitrogen content, \%} + A,$$

can be derived where A is a constant that depends on variety. These constants turn out to be 54.9 for Bison, 52.4 for Royal, and 51.1 for Redwing. Since the three varieties have very similar mean nitrogen contents, it is evident that these constants must reflect the observed differences among the mean values for oil content. If these equations are employed, oil content can be estimated from total nitrogen with a standard error of $\pm$ 0.57%.

The relation between 1000-kernel weight and oil content ($r = .4974^{**}$) was shown previously to result mainly from common association of these properties with total nitrogen. Consequently, it appears that no advantage would be obtained by combining nitrogen and 1000-kernel weight in equations for the estimation of oil content. The multiple correlation coefficient ($R = .8329^{**}$) was computed and as expected it was found that this value is not significantly higher than the simple coefficient ($r = -.8167^{**}$) for the relation between nitrogen and oil content. It thus appears that no simple direct prediction for oil content can be devised from the properties studied.

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CANADIAN LINSEED

II. RELATIONS BETWEEN IODINE VALUE AND FATTY ACID COMPOSITION OF LINSEED OIL[1]

By H. R. Sallans[2] and G. D. Sinclair[3]

Abstract

Analyses were made for non-saponifiable matter, iodine value, thiocyanogen value, and saturated acids on 54 samples of linseed oil from three varieties of flax grown in Saskatchewan. From these data the percentages of oleic, linoleic, and linolenic acids in the oils were computed. Analysis of variance showed that varietal differences exist for all these properties with the exception of non-saponifiable matter, and environmental effects cause significant differences in all properties.

Highly significant total correlation coefficients were obtained between iodine value and:—thiocyanogen value, $r = .962^{**}$; saturated acids, $r = -.596^{**}$; unsaturated acids, $r = .692^{**}$; oleic acid, $r = -.912^{**}$; and linolenic acid, $r = .940^{**}$. Relations between iodine value and thiocyanogen value, linolenic acid, linoleic acid, and oleic acid proved to be homogeneous with respect to regression coefficients and centroids. From these relations the following prediction equations were derived:

Thiocyanogen value = 0.44 iodine value + 38.59 (*S.e.* = 0.63 units);
Linolenic acid, % = 0.49 iodine value − 37.93 (*S.e.* = 0.88%);
Linoleic acid, % = 0.055 iodine value + 0.73 (*S.e.* = 1.80%);
Oleic acid, % = −0.48 iodine value + 113.08 (*S.e.* = 1.06%).

** *Indicates that the 1% level of significance was attained.*

The present scarcity of tung oil has led to a marked increase in the processing of other drying and semi-drying oils to produce substitutes for use in fast drying and weather-resistant surface coatings. These developments include fractionation by liquid–liquid extraction (14), polymerization by heating, with subsequent solvent fractionation (1) or molecular distillation (5), and the production of oils having conjugated ethylenic linkages similar to tung oil (2, 4). All these processes are based on reactions involving the more highly unsaturated acid in the oils. In direct liquid–liquid extraction the more unsaturated glycerides are concentrated to produce a superior drying product; in processes involving heat treatment these glycerides are first polymerized and then concentrated through differential solubility of the products, and in treatments to induce conjugation it is obvious that only glycerides containing the more highly unsaturated acids are involved. It is thus apparent that methods for the estimation of the various unsaturated fatty acids in oils are becoming of greatly increased importance in the drying oil field.

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[2] *Biochemist, Oil Seeds Laboratory, University of Saskatchewan.*
[3] *Laboratory Assistant, Oil Seeds Laboratory, University of Saskatchewan.*

The usual methods for the determination of the unsaturated acids, oleic, linoleic, and linolenic, are difficult and time consuming and are not suited to rapid control work in processing plants. In general, iodine values and refractive indices (6, 10, 16) are used for this purpose. It is obvious that these properties indicate the total unsaturation of the oils and unless a close relation exists between total unsaturation and the relative proportions of the various unsaturated acids these methods fail to reflect the value of an oil for processing. Consequently, an investigation was undertaken to determine the relations existing between iodine value of linseed oil and its constituent fatty acids.

Materials

Samples selected for this study consisted of the varieties, Bison, Royal, and Redwing, produced at 35 stations in Saskatchewan (15). Previous studies on this material showed a comparatively narrow range in iodine values, and in view of the small samples available it was decided to composite them to reduce the work involved and secure larger samples. The stations were arranged in order of mean iodine value, and since none of the adjacent pairs differed significantly in this property, they were composited. This procedure furnished 54 samples, 18 of each variety representing corresponding environments. A list of the composites is shown in Column 1 of Table II.

Methods

In spite of numerous investigations the method devised by Kaufmann (9) remains the most reliable and generally used procedure for the estimation of unsaturated acids in vegetable oils. This method is based on the assumption that iodine values indicate total unsaturation, the thiocyanogen values reflect total unsaturation of oleic acid, one-half that of linoleic acid, and two-thirds that of linolenic acid. Thus it becomes possible to set up simultaneous equations, combining iodine and thiocyanogen values with total unsaturated acids, which on solution yield values for the percentages of the various fatty acids. It has been shown (11, 12) that Kaufmann's assumption regarding thiocyanogen values is not strictly correct and as a result much of the earlier data cannot be considered accurate (13). With the development of fractional crystallization at low temperatures (3) it has been possible to prepare unsaturated fatty acids without danger of rearrangement and to establish the form occurring in natural oils. This has resulted in a modification of Kaufmann's original theoretical thiocyanogen values for linoleic and linolenic acids (11, 12), and the development of equations that yield satisfactory analytical data on known mixtures containing these acids (11).

Under the conditions used in the present investigation the equations employed were:

$$273.3\,x + 181.1\,y + 89.9\,z = 100\ I.V.$$
$$166.7\,x + 97.0\,y + 89.9\,z = 100\ T.V.$$
$$x + y + z = u,$$

where x = linolenic acid, %; y = linoleic acid, %; z = oleic acid, %; $I.V.$ = iodine value, Wijs; $T.V.$ = thiocyanogen value, and u = unsaturated acids, %. On solution the following expressions are obtained for the various unsaturated acids:

$$\text{Linolenic acid, \%} = 1.599\ T.V. - 0.125\ I.V. - 1.326\ u;$$
$$\text{Linoleic acid, \%} = 1.347\ I.V. - 3.216\ T.V. + 1.681\ u;$$
$$\text{Oleic acid, \%} = 1.617\ T.V. - 1.223\ I.V. + 0.645\ u.$$

Preparation of Oil Samples

Oil samples were prepared by pressing 200 gm. of finely ground flaxseed at room temperature in a Carver laboratory press at hydraulic pressure of approximately 15,000 lb. per square inch. Pressings were made in a standard $2\frac{1}{4}$ in. cylinder carrying a charge of approximately 70 gm. of ground flaxseed. The oil was centrifuged for 10 min. at 3000 r.p.m., transferred to a 50 ml. vial and stored in a household refrigerator maintained at 3° C. till all analyses were completed. A working schedule was arranged so that in no case did the time elapsing between pressing and completion of the analyses exceed seven days.

Aliquots of the oils were tested for moisture content by heating a 2 gm. sample in a 50 ml. pyrex beaker for five hours in a vacuum oven at 100° C. The loss in weight under these conditions was always less than 0.1% and averaged about 0.05%. It appeared that this loss could readily be due to volatile matter in the oils, and subsequent analyses were made on the oil as it came from the press.

Iodine and Thiocyanogen Values

Iodine values were determined by the standard Wijs method with a one hour reaction time. This procedure has been shown to yield theoretical results for purified oleic, linoleic, and linolenic acids (11).

For thiocyanogen values the method of Matthews, Brode, and Brown (11) was employed with the exception that a reaction temperature of 21° C. ± .05 was used. A temperature of 16° C. is difficult to maintain, in the average laboratory, without expensive refrigeration equipment. It was found that a closed constant temperature bath, employing a heater controlled by a sealed mercury in glass thermoregulator balanced against an inflow of cold water from the laboratory main, could be used successfully for the determination. Tests indicated that so long as room temperature exceeded the bath temperature this equipment operated satisfactorily and no decomposition of the reagent occurred owing to the high humidities in the enclosed bath.

Unsaturated Acids

Unsaturated acids were determined by difference. Saturated acids were estimated by the modification of the Twitchell lead–salt–alcohol method outlined by Jamieson (8), but in decomposing the lead salts nitric acid was used instead of hydrochloric acid (7). The modified Kerr–Sorber method (8) was employed for the estimation of unsaponifiable matter. From the data on

these two determinations the percentage of unsaturated acids was calculated on the basis that 95.6% of the oil is composed of fatty acids. This method fails to take into account any non-glyceride constituents other than unsaponifiable matter. However, cold-pressed oil yields no break on heating, indicating that the content of mucilaginous material is extremely low, and it is doubtful if extraneous material would amount to more than 0.1% of the total oil. As a check on this assumption a number of samples were run by the lead–salt–ether method (8), in which the unsaturated acids are determined by direct weighing. It was found that results by the two methods agreed within the experimental error.

Precision of the Method

The standard error of the means of duplicate determinations was found to be ± 0.37 units for iodine value, ± 0.25 units for thiocyanogen value, and ± 0.18% for saturated acids. If the mean square errors for these determinations are substituted in the equations for oleic, linoleic, and linolenic acids, an estimation of the over-all precision of the method can be obtained. This procedure yields a standard error of ± 0.53% for oleic, ± 0.66% for linoleic, and ± 0.40% for linolenic acid.

Mean Differences Between Varieties and Composites

The data for non-saponifiable matter, iodine value, thiocyanogen value, saturated and unsaturated acids together with values computed from these data for oleic, linoleic, and linolenic acids are summarized in Table I as means for each variety, and in Table II as means for each set of composites. To determine whether or not the observed differences in the mean values are significant the data were subjected to analyses of variance, shown in Table III. From these analyses the extent to which the means must differ for odds of 19 to 1 (i.e., 5% level of significance) that a real difference exists were computed and are appended in the last lines of Tables I and II.

TABLE I

VARIETAL MEANS FOR OIL PROPERTIES

Variety	Non-saponifiable matter, %	Iodine value, Wijs	Thiocyanogen value, official	Saturated acids, %	Unsaturated acids, %	Oleic acid, %	Linoleic acid, %	Linolenic acid, %
Redwing	0.83	192.2	123.2	6.3	88.5	21.4	11.5	55.7
Bison	0.83	184.0	119.8	6.6	88.3	25.6	11.1	51.6
Royal	0.82	183.2	119.2	7.2	87.6	25.5	10.5	51.7
Necessary difference, 5% level	—	1.2	0.6	0.1	0.1	0.6	0.7	0.8

TABLE II

COMPOSITE MEANS FOR OIL PROPERTIES

Composited stations	Non-saponifiable matter, %	Iodine value, Wijs	Thiocyanogen value, official	Saturated acids, %	Unsaturated acids, %	Oleic acid, %	Linoleic acid, %	Linolenic acid, %
Tessier Mantario	0.78	182.4	118.9	7.1	87.7	25.9	10.7	51.1
Mullinger Prud'homme	0.79	182.6	119.2	6.9	87.9	26.8	9.6	51.4
Osler Birsay	0.82	182.9	119.0	7.1	87.7	25.4	11.2	51.2
Carmel Stoughton	0.84	184.5	119.3	6.7	88.0	24.2	12.8	51.1
Mont Nebo Mervin	0.83	185.5	119.6	6.7	88.1	23.6	13.0	51.4
Saskatoon Yellowgrass	0.78	185.9	120.9	6.7	88.1	25.0	9.8	53.3
Ceylon Allen	0.86	185.9	120.4	6.6	88.2	24.2	11.6	52.4
Drake Davidson	0.83	185.7	121.0	6.3	88.5	25.7	9.8	52.9
Eston Imperial	0.87	185.9	121.0	6.7	88.1	25.2	9.3	53.5
Holdfast Norquay	0.84	186.5	120.5	6.4	88.4	23.8	12.4	52.2
White Star Young	0.73	187.2	120.6	6.9	88.0	23.0	12.1	52.9
Govan Gibbs	0.88	187.4	122.1	6.3	88.5	25.5	8.3	54.7
Elbow Robinhood	0.91	188.4	120.7	6.4	88.3	22.3	13.1	52.9
Driver Davis	0.81	188.3	120.8	6.8	88.1	21.9	13.2	53.0
Rosetown Feudal	0.81	189.3	122.0	6.6	88.2	22.6	11.0	54.5
Maidstone Marshall	0.85	189.8	122.1	6.6	88.2	23.4	9.9	54.8
Sturgeon Valley Guernsey	0.82	190.2	122.0	6.8	88.0	21.5	11.6	54.8
Frenchman Butte	0.85	189.0	122.8	6.3	88.2	24.5	8.4	55.5
Mean	0.83	186.5	120.7	6.7	88.1	24.2	11.0	53.0
Range	0.18	7.8	3.9	0.8	0.8	5.3	4.8	4.4
Necessary difference, 5% level	0.04	3.0	1.6	0.3	0.3	1.5	1.6	1.9

Comparison of the variety means in Table I with the necessary differences indicate that real differences exist with respect to all properties listed with the exception of non-saponifiable matter. In general, it appears that linseed oils from the varieties Bison and Royal are very similar in composition, with Royal

TABLE III

ANALYSES OF VARIANCE FOR OIL PROPERTIES: MEAN SQUARES

Oil property	Variance due to:		
	Varieties	Composites	Interaction
Non-saponifiable matter, %	0.0001241	0.0056414**	0.0006080
Iodine value, Wijs	448.0153**[1]	16.49794**	3.274916
Thiocyanogen value, official	84.81806**	4.118317**	0.8970476
Saturated acids, %	3.612080**	0.193785**	0.373482
Unsaturated acids, %	4.088467**	0.144302**	0.032749
Oleic acid, %	106.00870**	6.694027**	0.7692805
Linoleic acid, %	4.629614*[1]	7.607002**	0.9619874
Linolenic acid, %	99.63491**	6.134871**	1.256682
Degrees of freedom	2	17	34

[1] *Throughout the text and in Tables III to V, ** denotes that the 1%, and * that the 5%, level of significance has been attained.*

showing slightly less unsaturation than Bison. This difference appears to be due primarily to a higher percentage of saturated and a correspondingly lower percentage of unsaturated acids in the oil from Royal flax. Redwing, which is characterized by a high iodine value, shows a lower value for saturated acids and oleic acid, with a higher value for unsaturated acids and linolenic acid.

The means for composites shown in Table II indicate that environmental effects produce significant differences in all the properties studied. It is evident from the data that certain of these properties appear to be closely related and these relations are discussed in greater detail in the following sections.

Correlation Studies

Total simple correlation coefficients among the oil properties were computed and are shown in Table IV. In addition to these correlation coefficients, the coefficients for composite means were also computed. Since these were for

TABLE IV

TOTAL SIMPLE CORRELATIONS AMONG OIL PROPERTIES

Oil property	Thiocyanogen value	Non-saponifiable	Saturated acids	Unsaturated acids	Oleic acid	Linoleic acid	Linolenic acid
Iodine value	.9616**	.1828	−.5959**	.6916**	−.9122**	.1508	.9403**
Thiocyanogen value		.1410	−.6303**	.7508**	−.7707**	−.1041	.9845**
Non-saponifiable			−.2221	.2598	−.1239	.0072	.1706
Saturated acids				−.9077**	.5796**	−.0121	−.4905**
Unsaturated acids					−.5013**	.0650	.6386**
Oleic acid						−.4989**	−.7472**
Linoleic acid							−.1884

the most part of similar magnitude and sign to the total coefficients, the latter values are used for purposes of the following discussion. The only outstanding differences in the two sets of coefficients were intravarietal coefficients of $r = -.6353^{**}$ between non-saponifiable matter and saturated acids, and $r = .5150^{*}$ between non-saponifiable matter and unsaturated acids. This would suggest that in considering a number of samples of a given variety these properties would be related, but, since the total correlations are not significant, i.e., $r = -.2221$ and $r = .2598$, respectively, the relations would not be generally applicable to all samples irrespective of variety. On the other hand, since the remaining coefficients are similar when determined either from the total data or from station means, it would appear that they represent relations that are in the main independent of the effects of variety.

In considering the coefficients in Table IV the most striking feature is the similarity between relations involving iodine and thiocyanogen values and the close association, $r = .9616^{**}$, between these latter values. This relation is illustrated graphically by means of a scatter diagram, Fig. 1, and it appears

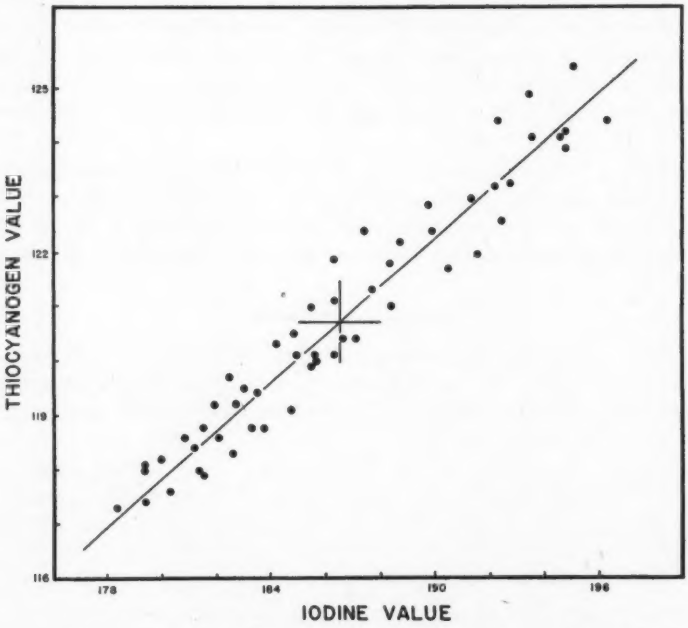

FIG. 1. *Regression of thiocyanogen value on iodine value of linseed oil.*

that it should be possible to estimate thiocyanogen values from iodine values. Since the saturated acids show a significant tendency to decrease with increase in iodine value, $r = -.5959^{**}$, it would naturally follow that unsaturated acids should increase. The values for oleic, linoleic, and linolenic acids were

computed from iodine values, thiocyanogen values, and total unsaturated acids and, since these latter properties are associated with each other, it is to be expected that relations would exist between iodine value and the individual unsaturated acids. It turns out that oleic acid shows a highly significant tendency to decrease with increasing iodine value, $r = -.9122^{**}$; linoleic acid shows no significant association, and linolenic acid shows a marked tendency to increase, $r = .9403^{**}$. Relations between iodine value and oleic and linolenic acids are illustrated graphically in Figs. 2 and 3, respectively.

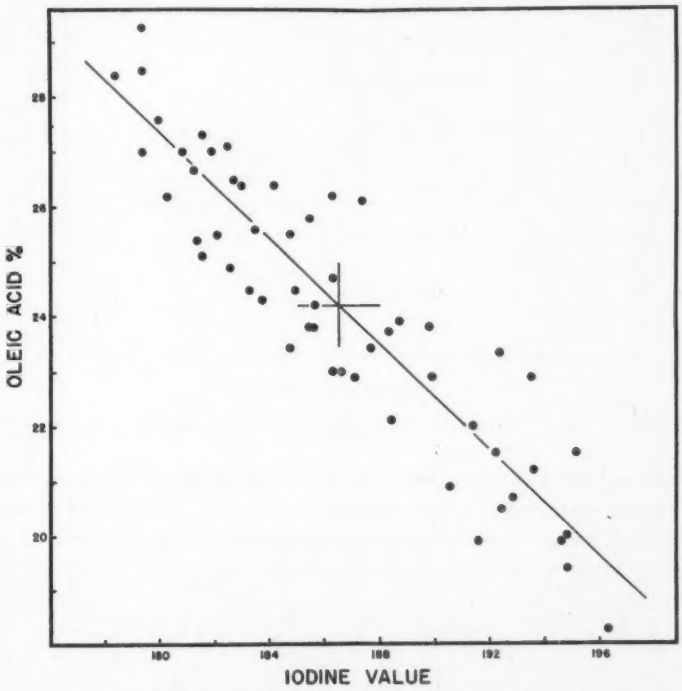

FIG. 2. *Regression of percentage oleic acid on iodine value of linseed oil.*

Saturated and unsaturated acids show a close negative association as would be expected and both these properties show significant associations with oleic and linolenic acids. Oleic acid tends to increase with increase in saturated acids and to decrease with increase in unsaturated acids. Coefficients between linolenic acid and saturated and unsaturated acids show similar associations of opposite sign. From the above relations it is logical to expect a negative association between oleic and linolenic acids; this is confirmed by a significant correlation coefficient, $r = -.7472^{**}$. In general, the correlation coefficients involving linoleic acid are not significant; the value, $r = .4989^{**}$, with oleic acid therefore appears to be a peculiar exception. A consideration

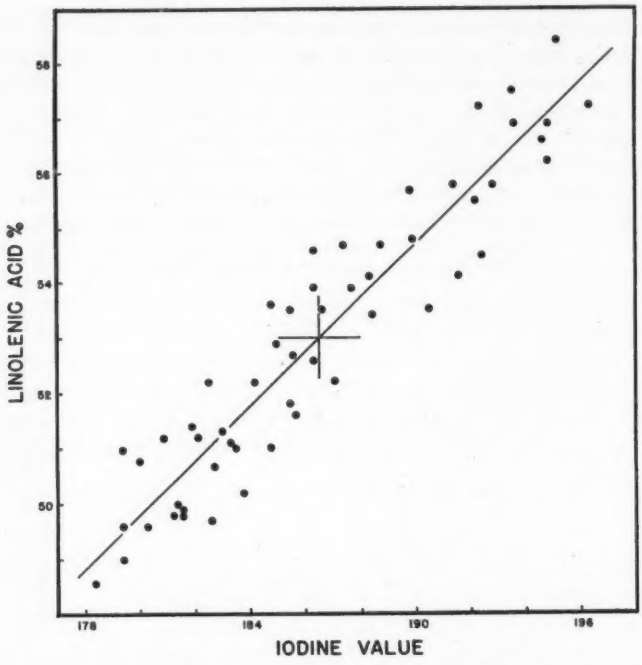

FIG. 3. *Regression of percentage linolenic acid on iodine value of linseed oil.*

of the equations used for computing the individual unsaturated acids suggests that this value may arise from the calculations. It is evident that a positive error in iodine value would result in a numerically greater positive error for linoleic acid, while in the case of oleic acid the error would be negative. A similar situation exists with respect to thiocyanogen values; a positive error results in a low value for linoleic acid and a high value for oleic acid. Since these errors are opposite in sign, it is reasonable to expect that they might give rise to the observed negative association between oleic and linoleic acids.

From the above relations it appears that definite regularities exist in the composition of the oils. Considering iodine value as the major property an increase in this value results in increases in thiocyanogen value, unsaturated acids and linolenic acid with a corresponding decrease in saturated acids and oleic acid.

Prediction Equations

Since definite regularities exist in the composition of linseed oil and the major properties are all related to iodine value, it appears that prediction equations may be developed to estimate these properties directly from iodine values. With this aim in view a more detailed investigation of these relations by means of regression equations was undertaken. The residual variance

remaining after fitting regressions was analysed into portions resulting from (i) differences among varietal regressions, (ii) deviations of varietal means from average varietal regressions, and (iii) residual deviations from individual varietal regressions. Results of these analyses of residual variance for regression of thiocyanogen value, linolenic, linoleic, and oleic acids, and saturated and unsaturated acids on iodine value are shown in Table V.

TABLE V

ANALYSES OF RESIDUAL VARIANCE FOR VARIETAL REGRESSION OF OIL PROPERTIES ON IODINE VALUE: MEAN SQUARES

Oil property	Variance due to:			Total regression coefficient
	Differences among varietal regression coefficients	Deviation of varietal means from average regression	Residual deviations from individual varietal regressions	
Thiocyanogen value	0.563995	0.231382	0.411706	.4404
Linolenic acid	0.337788	1.697742	0.751153	.4876
Linoleic acid	0.396380	1.254773	1.162869	.0550
Oleic acid	1.168897	2.725393	3.32498	−.4769
Saturated acids	0.116514	1.643480**	0.085045	−.0570
Unsaturated acids	0.130805	1.381792**	0.49283	.0660
Degrees of freedom	2	2	48	52

** *Exceeds mean square residual, 1% level of significance.*

The relation between iodine value and thiocyanogen value, $r = .9616$**, illustrated in Fig. 1, was broken down into four graphs shown in Fig. 4. These graphs present the relation by varieties and by station means over all varieties. Examination of the figure indicates that the slopes of the regression lines are all similar. Reference to Table V confirms this, since the analysis of residual variance for this relation indicates that varietal regressions do not differ significantly and that they can all be represented by the average varietal regression. Furthermore, since the varietal means do not deviate significantly from the average varietal regression, it follows that the total regression will not differ significantly from the average regression. The numerical values for these regression coefficients were 0.44 and 0.45, respectively. It thus appears that on the average an increase of one unit in iodine value is associated with an increase of 0.44 units in thiocyanogen value and that this relation is equally valid for the three varieties studied. From these considerations it is obvious that the relation may be accurately represented by a single simple regression equation of the type, $y = m\,x + b$. This equation was derived and turned out to be:

$T.V. = 0.4404\ I.V. + 38.59$ ($S.e. = \pm 0.63$ units) where $T.V.$ = thiocyanogen value, $I.V.$ = iodine value, and $S.e.$ = standard error of estimate. Considering the analytical errors for both determinations, it is

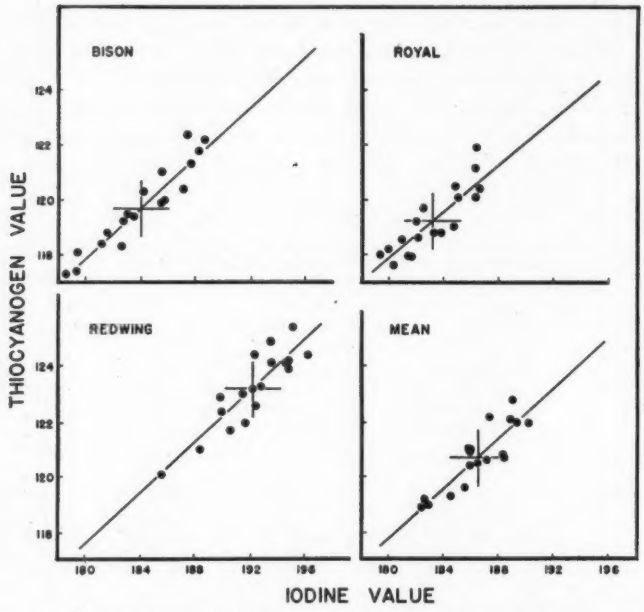

FIG. 4. *Varietal regressions of thiocyanogen value on iodine value of linseed oil.*

evident that thiocyanogen values can be estimated from this relation with a high degree of accuracy.

The association between iodine value and linolenic acid was analysed in a similar manner and thé relation is presented by means of graphs in Fig. 5. The prediction equation is:

$$\text{Linolenic acid, } \% = 0.4876\ I.V. - 37.93\ (S.e. = \pm\ 0.88\%).$$

The relation between iodine value and oleic acid, illustrated in Fig. 3, could be broken down into a series of varietal graphs. In this case the figure would resemble that shown in Fig. 5, with the exception that the slopes of the regression lines would be negative instead of positive. Reference to Table V will show that varietal regressions do not differ and that the varietal means do not deviate significantly from the average regression. Hence this relation may be represented by the equation:

$$\text{Oleic acid, } \% = -\ 0.4769\ I.V. + 113.08\ (S.e. = \pm\ 1.06\%).$$

The relation between linoleic acid and iodine value is not significant, $r = .1508$, and it would seem that for prediction purposes a constant value for linoleic acid could be assumed. However, data published on the composition of seven American linseed oils by Rose and Jamieson (13) suggest a tendency for linoleic acid to increase with iodine value. Their study covered a range in iodine value of 144.1 to 197.3 units and it appears reasonable to assume that, if a wider range in iodine value had been used in the present

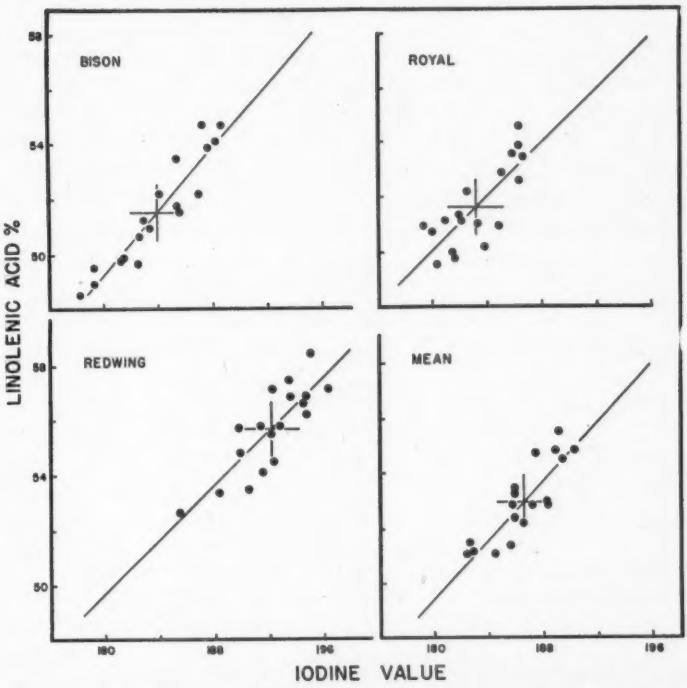

FIG. 5. *Varietal regressions of percentage linolenic acid on iodine value of linseed oil.*

study, a significant correlation would have been obtained. In this connection it should also be noted that in the equations for calculating the unsaturated acids, the equation for linoleic acid results in the highest errors, which would lower the value of the observed correlation coefficient. Therefore, in spite of the lack of a significant correlation, the data were subjected to analyses of residual variance shown in Table V and the following equation was derived:

$$\text{Linoleic acid, } \% = 0.055\ I.V. + 0.73\ (S.e. = \pm\ 1.80\%).$$

The total correlation coefficients of saturated and unsaturated acids with iodine value, $r = -\ .5959^{**}$ and $r = .6916^{**}$, are not sufficiently high to permit the development of accurate prediction equations. However, these relations were subject to analyses of residual variance, reported in Table V, to further elucidate the nature of the associations. It is evident that while the regressions of these properties on iodine value show no significant differences due to variety, the varietal means deviate significantly from the average regressions. The average regression of saturated acids on iodine value was $-.025$, and of unsaturated acids on iodine value was 0.055. Thus within a variety an increase of one unit in iodine value is accompanied by an average decrease of .025% in saturated acids and an average increase of 0.055% in unsaturated acids.

General Discussion

Using the equations and relations developed in the previous sections and applying them to two samples of linseed oil having iodine values of 180 and 190, respectively, we obtain the data shown in Table VI for the distribution of fatty acids. It will be noted that the major variations in composition occur in the linolenic and oleic acid fractions and that an increase of 10 units in iodine value gives an increase of 4.9% in linolenic acid, which is accompanied by an equivalent decrease of 4.8% in oleic acid.

TABLE VI

DATA SHOWING THE INFLUENCE OF AN INCREASE OF 10 UNITS IN IODINE VALUE ON THE COMPOSITION OF LINSEED OIL

Fatty acids	Linseed oil, iodine value of:		Difference due to 10 units, iodine value
	180 units	190 units	
Linolenic acid, %	49.8	54.7	+ 4.9
Linoleic acid, %	10.6	11.2	+ 0.6
Total, strongly drying components	60.4	65.9	+ 5.5
Oleic acid, %	27.3	22.5	− 4.8
Saturated acids, %	7.1	6.5	− 0.6
Total, non-drying components	34.4	29.0	− 5.4

In the drying of oils linolenic and linoleic acids are the most reactive constituents, while oleic acid and the saturated acids are virtually inert and of minor importance. Thus, it appears that as iodine values increase the reactive drying constituents increase and at the same time the relatively inert constituents decrease. From these considerations it is evident that a comparatively small change in iodine value should result in a marked change in the rate at which an oil will dry and in the nature of the film produced. The films from high iodine oil are known to dry more rapidly and produce harder and more durable surfaces. Unfortunately, the problem of accurately measuring the drying time of raw linseed oil is complicated by a relatively long induction period due to the presence of natural antioxidants. Some workers even go so far as to state that it is impossible to obtain reliable estimates of this property. However, in the processing of oils most of these antioxidants are destroyed and the drying phenomena become a function of the composition of the oil. In the fractionation of linseed oil and the production of tung oil substitutes it is, therefore, obvious that the use of high iodine oil should increase the yield of drying products produced and also the polymerization properties of any processed oil. The net effect of a 10 unit increase in iodine value is to substitute 5% of inert materials by 5% of highly reactive fatty acids.

In the edible oil and soap industries if a sufficiently acute shortage of vegetable oils occurs, it may be necessary to incorporate a percentage of linseed

oil in the products. From the foregoing discussion it appears that oils having the lowest possible iodine values should be employed. By this means the linolenic acid content would be reduced and the numerous difficulties in processing, i.e., hydrogenation, obtaining suitable consistency, and the production of stable products would be reduced.

The relations presented in this paper are based on iodine values but, if suitable procedures (6, 10, 16) are used in preparing the oils, equally valid relations would exist between the constituent acids and the refractive index of the oil. It thus appears that comparatively simple and rapid routine procedures using prediction equations based on the regularity in the composition of linseed oil can be developed for control analyses in processing plants. Furthermore, if the present critical shortage of vegetable oils continues it may be advantageous to segregate or grade the flax crop, which normally shows a range of approximately 20 units, on the basis of iodine values.

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CANADIAN LINSEED

III. IODINE VALUES IN RELATION TO OIL AND MEAL PROPERTIES OF COMMERCIAL SAMPLES

By H. R. Sallans

Abstract

Commercial samples of the 1942 flax crop were collected and composited into a series of 12 composites ranging in iodine value from 182 to 198 units. Analyses of these composites were made to determine what effect a grading system based on iodine values would have on the composition of linseed oil and meal.

The data indicate that for these samples the iodine number of the oil provides a reliable index of the fatty acid composition, irrespective of the variety or the environmental conditions under which a particular sample is produced. Thus iodine value of the oil is a reliable factor on which to base a premium grade of Canadian linseed.

It is shown that the establishment of such a grade would result in lower oil yield and lower protein content in the cake from this flax. This is due to the effects of variety and environment on the iodine value of linseed oil and may be corrected by the development of new varieties that are adapted to northern areas and have a high oil content.

In processing linseed oil for the production of heat-bodied oils it is well known that oils of high iodine value require shorter heating periods and show lower losses of volatile materials during this process. Furthermore, the final product gives harder finishes and more rapid drying when used in the production of varnishes and printing inks. Manufacturers of linoleum and oil processors, making specialized fast drying oils for use in surface coatings, express a preference for oils having high iodine values. And, since recent researches indicate that high drying oil fractions separated by liquid–liquid extraction yield superior products to heat-bodied oils (7), an increasing interest in linseed oil of high iodine value is to be expected.

From the Canadian viewpoint this is a desirable development since Canadian linseed is recognized as producing oil of high quality. However, in contrast with processors who show a preference for linseed oil having a high iodine value, others interested in the production of soft soaps, edible products, and exterior paints (where fast drying is not a primary requisite and where tough elastic films are desirable) would in all probability be better satisfied with oil of lower iodine value.

In anticipation of a demand for linseed oil having an exceptionally high iodine value, the suggestion has been made that a special grade of linseed be created, based on iodine value of the oil. It therefore appeared desirable to investigate the effects on the composition of linseed oil and meal if such a

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[2] *Biochemist, Oil Seeds Laboratory, University of Saskatchewan.*

grade were established. Some preliminary work towards this end has been reported in studies of the effects of variety and environment on the composition of linseed (10), and the relations between iodine value and fatty acid composition (11) of the oils from the three principal varieties at present being produced in Canada. With this material as a background to assist in the interpretation of the data the present study based on commercial samples was undertaken.

Materials and Methods

Materials

The samples for this investigation were collected from commercial grain companies and from the inspection offices of the Board of Grain Commissioners for Canada in an annual survey of "The Quality of Western Canadian Flax 1942 Crop" (4). In addition to samples collected for this survey a number of individual samples from subsequent deliveries were obtained from the inspection offices to bulk out the higher and lower ranges in iodine value and provide representative samples of sufficient size for analysis. These samples were then arranged in groups, according to iodine value as determined from refractive index, and composited. Over the central portion of the range the individual samples composited did not vary by more than one or two units in iodine value, while in the higher and lower ranges individual samples in a composite may vary by five to six units in iodine value. A list of these composites together with the number of samples in each and the iodine values as determined by the Wijs procedure are shown in Table I.

From a survey of the varietal composition of the 1942 crop, obtained by growing composite samples of all carlots inspected in the first half of the

TABLE I

DATA ON OIL AND FLAX PROPERTIES OF 12 COMPOSITES BASED ON IODINE VALUES, 1942 CROP

Composite No.	Samples in composite	Oil property				Flax property		
		Iodine value	Acid value	Saponification equiv.	Oil content, %	Total nitrogen, %	Ash, %	1000-Kernel wt., gm.
1	13	182.0	0.59	188.2	41.2	4.20	3.41	5.33
2	12	184.5	0.55	188.6	41.1	4.02	3.32	5.30
3	48	186.3	0.50	188.7	41.7	3.92	3.35	5.42
4	30	188.1	0.49	188.6	42.3	3.83	3.42	5.49
5	41	188.5	0.40	188.3	41.8	3.90	3.45	5.27
6	43	189.8	0.48	188.6	41.7	3.87	3.47	5.02
7	28	191.3	0.43	188.0	41.5	3.79	3.51	5.11
8	26	192.3	0.48	188.5	41.1	3.83	3.56	4.76
9	23	193.7	0.44	188.3	41.5	3.77	3.53	4.86
10	17	193.9	0.38	188.9	40.7	3.81	3.50	4.69
11	13	195.5	0.37	188.3	41.0	3.73	3.60	4.81
12	19	198.1	0.38	188.6	40.7	3.72	3.58	4.76
Mean	26	190.3	0.46	188.4	41.4	3.86	3.86	5.07
S.e. of estimate for individual values		0.3	0.03	0.3	0.2	0.03	0.03	0.04

crop year (1), it appears that the varieties were produced in the following amounts: Redwing, 35.1%; Bison, 46.8%; Royal, 15.0%; and other varieties, 3.1%. It has been shown previously (10) that, when a large area is considered, the varieties Royal and Bison produce oils having essentially the same average iodine values, with Royal tending to be slightly lower than Bison. Redwing on the other hand yields oil having an average iodine value of seven to eight units higher than either of the other two varieties. From these considerations it is obvious that the composites in a series such as that shown in Table I will not be homogeneous with respect to varietal composition. It is to be expected that the composites of lower iodine value will be composed almost entirely of the varieties Bison and Royal, while those in the upper range will be almost exclusively Redwing. The intermediate range will be a mixture of all three varieties with Bison predominant. This variation in varietal composition must be kept clearly in mind when the data on this series are considered and will be referred to in the subsequent discussion to explain apparent differences between studies on samples of pure varieties and those from commercial sources containing a mixture of varieties.

Analytical Methods

The methods employed for iodine value, thiocyanogen value, saturated acids, non-saponifiable matter, and the estimation of fatty acid distribution have been described in Part II (11) of this series. Commonly measured properties of linseed, such as total nitrogen, 1000-kernel weight, oil content, and refractive index of the oil, were determined by methods described in Part I (10).

Crude fibre was determined on oil free residues by the official method of the A.O.A.C. (6). Pentosan content was estimated by conversion to furfural and distillation as outlined in the official A.O.A.C. method (6). However, in place of the usual phloroglucinol precipitation, furfural was determined in the distillate by means of a sodium-bromate–bromide reagent and converted to pentosan by use of the factor 1.80 (9). For the determination of ash, 1 gm. samples of whole seed were ashed at 550° C.

Replication

The usual analyses for oil content, nitrogen, ash, fibre, etc. were determined on duplicate aliquots drawn from the main bulk of the composites. In the case of iodine value, thiocyanogen value, non-saponifiable matter and saturated acids, determinations were made on triplicate aliquots drawn from the main samples. Thus, three separate samples of oil from each composite were secured and single determinations on each sample were made. This procedure was adopted to reduce sampling and analytical errors to a minimum in the estimation of the acid fractions in the oils. Even with this precaution the errors of estimate for linolenic, linoleic, and oleic acid approach a value of 1.0%.

Results

Oil and Flax Properties

In Table I data on iodine value, acid value, and saponification equivalent of oils from the 12 composites are given together with oil content, total nitrogen, ash, and 1000-kernel weight determined on the total seed. Standard errors for the means of duplicate determinations shown in the last line of the table indicate that real differences exist between the composites for all the properties listed with the single exception of saponification equivalent. Certain regular trends in the other factors with increase in iodine value of the composites may be noted from the data in Table I, and, to facilitate the examination and discussion of these relations, simple correlation coefficients were computed and are shown in Table II.

TABLE II

SIMPLE CORRELATION COEFFICIENTS AMONG OIL AND FLAX PROPERTIES FOR 12 COMPOSITES BASED ON IODINE VALUE

Property	Acid value	Oil content, %	Total nitrogen, %	Ash, %	1000-Kernel wt., gm.
Iodine value, Wijs	−.872**[1]	−.438	−.914**	.884**	−.843**
Acid value		.282	.849**	−.729**	.646**[2]
Oil content, %			.011	−.422	.720**
Total nitrogen, %				−.730**	−.616*
Ash, %					−.839**

[1] *Throughout the text and in Tables II, IV, and VI, ** denotes that the 1% level of significance has been attained.*

[2] *In this and subsequent tables * indicates that the 5% level of significance has been attained.*

It is evident from the data in Tables I and II that, as iodine value increases, acid value of the oil, total nitrogen, and 1000-kernel weight show a highly significant tendency to decrease. There is also a tendency for oil content to decrease, although the correlation coefficient, $r = -.438$, fails to attain a significant value. As contrasted with these properties, ash content shows a highly significant tendency to increase with increasing iodine value.

The trends in iodine value and 1000-kernel weight are obviously due to the tendency of the variety Redwing to concentrate in the composites of higher iodine value, since it has been shown previously that Redwing is significantly higher in iodine value and lower in 1000-kernel weight and oil content than either of the other two varieties. For similar reasons a tendency for oil content to decrease with increasing iodine value would be expected. The failure of the correlation coefficient to attain significance appears to be due to other factors affecting the relation. Reference to Part I (10) shows that within a variety 1000-kernel weight and oil content are associated ($r = .497$**), while there is no apparent association of 1000-kernel weight and iodine value. An examination of Table I shows that in Composites 9

and 11 there is a tendency for 1000-kernel weight and oil content to be out of line with corresponding iodine values. This discrepancy may arise from the differences in the associations of iodine value with oil content and 1000-kernel weight, or it may be due to a concentration of samples of Bison of outstanding iodine values in these two composites. These possibilities are substantiated by the high correlation coefficient, $r = .720^{**}$, obtained between 1000-kernel weight and oil content as compared to that within a single variety, $r = .497^{**}$, from the previous study on pure varieties.

When the varieties were grown under the same environments, no significant differences were noted in total nitrogen. Hence, the high negative association, $r = -.914^{**}$, between iodine value and total nitrogen cannot be explained as due to varietal effects. It must, therefore, be due to other influences and it appears that this relation stems from the adaptation of varieties to specific areas. Thus, the variety Redwing, which has a high iodine value, is considerably earlier in maturity than either of the other two varieties and is grown in greater proportion in the more northerly areas. Under these conditions of lower temperature and higher moisture there is a definite tendency to the production of high values for iodine number and oil content coupled with low nitrogen content. It would, therefore, appear that the observed association is due to this effect. Similar explanations would apply to the negative association between total nitrogen and 1000-kernel weight.

No clear-cut explanation for the associations of acid value of the oil and ash content of the seed with other properties can be given, since varietal and environmental effects on these properties have not been investigated. However, there may be some justification for the opinion that higher nitrogen content in the seed is associated with higher levels of fat splitting enzymes, since associations between nitrogen and enzymatic activities have been demonstrated in studies on barley (5). In the case of the association between ash and 1000-kernel weight, $r = -.839^{**}$, there is a definite tendency for large-seeded composites to be low in ash content. This is not surprising since seed size shows a positive association with oil content and the latter property would not contribute materially to ash content. It is also quite possible that varietal differences in these properties may also be a factor contributing to the observed associations.

No differences in saponification equivalent could be detected between composites. A calculation of the change in molecular weight of the glycerides, due to an increase of 16 units in iodine value, indicates that it would be impossible to detect this difference by the method employed. And, since by far the largest portion of the fatty acids in linseed oil have 18 carbon atoms, it would not be expected that saponification values would reflect changes in the amounts of a minor constituent such as palmitic acid.

Oil Properties

In Table III data for thiocyanogen value, saturated acids, unsaturated acids, and non-saponifiable matter together with the data for percentages of linolenic, linoleic, and oleic acids in the oils are shown. The standard errors

TABLE III

DATA ON THE FATTY ACID DISTRIBUTION IN THE OILS FROM 12 COMPOSITES BASED ON IODINE VALUES

Composite No.	Thiocyanogen value	Saturated acids, %	Unsaturated acids, %	Non-saponifiable matter, %	Linolenic acid, %	Linoleic acid, %	Oleic acid, %
1	119.4	6.27	88.6	0.72	50.6	10.1	27.9
2	120.9	6.38	88.5	0.76	52.9	8.4	27.2
3	121.6	6.11	88.8	0.74	53.4	9.1	26.2
4	122.5	5.95	88.9	0.73	54.4	9.0	25.6
5	122.7	6.03	88.9	0.73	54.8	8.6	25.5
6	123.4	6.12	88.8	0.74	55.9	8.0	24.9
7	123.7	5.90	89.0	0.76	56.0	9.4	23.7
8	124.5	5.74	89.1	0.76	56.9	8.5	23.8
9	125.2	5.89	89.0	0.77	58.1	7.7	23.2
10	125.2	5.64	89.2	0.80	57.6	8.6	22.9
11	126.0	5.68	89.2	0.77	58.8	8.0	22.3
12	127.3	5.52	89.3	0.78	60.3	7.7	21.3
Mean	123.5	5.94	88.9	0.76	55.8	8.6	24.5
S.e. of estimate for individual values	0.2	0.15	0.2	0.02	0.8	1.2	0.9

of the means of triplicate analyses are listed in the last line of the table and indicate that real differences between the composites exist for all properties listed. To facilitate comparison and discussion of these properties simple correlation coefficients among these properties and iodine value were computed. These coefficients are shown in Table IV. The close interrelation of these properties is evident from the high values for the correlation coefficients. Of the 21 values shown in Table IV, 18 attain the 1% level, 1 the 5% level, and two fail to attain a significant level.

The exceptionally high value of the correlation coefficient, $r = .999^{**}$, between iodine and thiocyanogen values indicates that 99.8% of the variance in thiocyanogen values can be accounted for by the variance in iodine values.

TABLE IV

SIMPLE CORRELATION COEFFICIENTS AMONG OIL PROPERTIES AND FATTY ACID COMPOSITION FOR 12 COMPOSITES BASED ON IODINE VALUE

Property	Thiocyanogen value	Saturated acids, %	Unsaturated acids, %	Linolenic acid, %	Linoleic acid, %	Oleic acid, %
Iodine value, Wijs	.999**	−.928**	.941**	.995**	−.710**	−.996**
Thiocyanogen value		−.918**	.930**	.998**	−.743**	−.990**
Saturated acids, %			−.993**	−.891**	.462	.941**
Unsaturated acids, %				.906**	−.482	−.949**
Linolenic acid, %					−.777**	−.984**
Linoleic acid, %						.654*

This is a surprisingly close association and would suggest that any slight irregularities might arise from experimental errors of analyses. A comparison of this coefficient with that obtained for this relation within pure varieties, $r = .982^{**}$ (11), could be explained on the basis of reduction in experimental error due to increased replication in the analytical determinations, and a reduction in variation in the materials due to compositing a number of different samples. Some workers (8) have taken the view that this relation is fundamental and in determining thiocyanogen values they have adopted the procedure of discarding values that deviate appreciably from a straight line relation with iodine values. A more intensive examination of this relation suggests that it is not due to a fundamental relation between iodine and thiocyanogen values. It has been shown (12) that linseed oil can be separated into fractions containing glycerides of a varying degree of unsaturation by chromatographic adsorption, and that these fractions differ by a single ethylenic linkage in their glyceride structure. If theoretical iodine and thiocyanogen values are computed for these fractions and the values plotted, they do not fall on a straight line but the increase in thiocyanogen values with iodine values falls into a step-like pattern. It therefore follows that the observed association of thiocyanogen and iodine values must be due to regular relations between the quantities of unsaturated acids present in the oils rather than to fundamental relations between these properties.

The remaining correlation coefficients in Table IV show that these regularities exist. Reference to Part II (11) indicates that in the case of the unsaturated acids, linolenic, linoleic, and oleic, the varietal regressions of these properties on iodine value do not differ significantly. Hence, in considering commercial shipments of Western Canadian flax, which may differ in varietal composition and point of origin, it is evident that these relations between iodine values and fatty acid composition will be applicable. A processor of Canadian linseed oil can, therefore, regard iodine value as a reliable index to the relative proportions of the various unsaturated fatty acids present in any lot of commercial linseed oil. If the iodine values are determined on cold-pressed oil, the relations presented in Table IV and graphically in Fig. 1 could be used directly to estimate fatty acid composition. The regression coefficients "*b*", i.e., the rate of increase or decrease in composition for unit increase in iodine value, are shown in Fig. 1. If commercially expressed oils are used a slight amount of polymerization of the unsaturated acids occurs owing to heat in the processing, which will alter the observed regressions slightly. However, if oil is consistently obtained from the same source, employing a standardized processing procedure, similar relations of this type should hold for commercial oils.

Meal Properties

Protein content, percentage ash, crude fibre, nitrogen free extract, and pentosans were determined on the basis of 5% oil and 10% moisture in the press cake. These data are shown in Table V. For linseed oil the accepted index of quality is its iodine value while for linseed meal the index is total

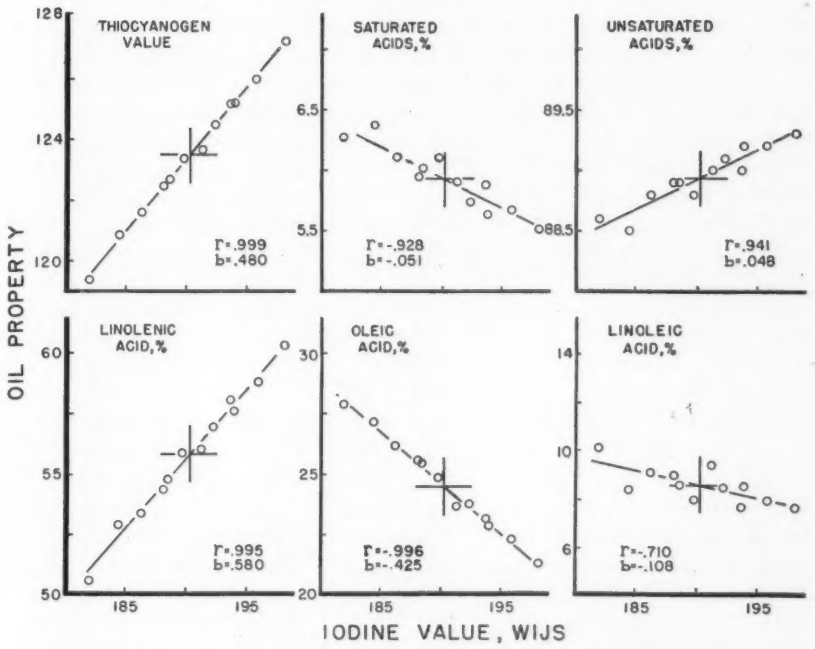

FIG. 1. *Regression of oil properties on iodine value for 12 composites of commercial samples from the 1942 crop.*

TABLE V

DATA ON MEAL PROPERTIES, AT 5% OIL AND 10% MOISTURE, FROM 12 COMPOSITES BASED ON IODINE VALUE

Composite No.	Protein, %	Ash, %	Crude fibre, %	Nitrogen free extract, %	Pentosan, %
1	37.9	4.93	6.71	35.4	14.2
2	36.3	4.79	7.42	36.5	14.4
3	35.7	4.88	7.56	36.8	14.8
4	35.2	5.03	7.67	37.1	15.0
5	35.6	5.04	7.82	36.5	14.8
6	35.3	5.06	8.05	36.6	14.9
7	34.4	5.10	7.86	37.6	15.1
8	34.5	5.13	8.08	37.0	15.3
9	34.2	5.13	7.80	37.8	15.1
10	34.2	5.02	8.19	37.6	15.0
11	33.6	5.19	8.31	37.9	15.1
12	33.3	5.13	8.08	38.5	15.2
Mean	35.0	5.04	7.80	37.1	14.9

protein content. To relate meal quality to oil quality the simple correlation coefficient between these two properties was computed and found to be, $r = -.968^{**}$. This coefficient and the data in Tables I and V show that as

oil quality (determined from iodine values) improves, meal quality (as measured by total protein content) decreases. From a consideration of the correlation coefficients in Table II and the discussion in a previous section, it is evident that two factors contribute to this association: (1) growing conditions conducive to the production of high iodine values tend to produce a flax of low protein content; (2) Redwing flax, which has a higher iodine value, does not differ from Bison and Royal in total nitrogen content but has a lower oil content. Hence, the meal from this variety will be lower in protein and this will result in a poorer quality of meal from composites showing oil of high iodine value.

Interrelations of the meal properties, usually estimated in feeding analyses, are presented in Table VI by means of simple correlation coefficients. These

TABLE VI

SIMPLE CORRELATION COEFFICIENTS AMONG LINSEED MEAL PROPERTIES FOR 12 COMPOSITES BASED ON IODINE VALUE

Property	Ash, %	Crude fibre, %	Nitrogen free extract, %	Pentosan, %
Protein, %	−.762**	−.902**	−.961**	−.915**
Ash, %		.687*	.651*	.786**
Crude fibre, %			.768**	.856**
Nitrogen free extract, %				.818**

coefficients show that, as protein content in the meal increases, ash, crude fibre, nitrogen-free extract, and pentosans decrease. The positive associations among the properties, ash, crude fibre, nitrogen-free extract, and pentosans, would appear to arise naturally from the high negative association of all these properties with protein content. This suggests that protein is the fundamental property governing the composition of the meal and that its use as an index of the feeding value of the meal has a valid foundation. The inference might be drawn that a high protein meal would require a greater addition of mineral or ash constituents for the production of a balanced feed. However, the data are not sufficient to warrant this conclusion as no information on the relative proportions of the various mineral constituents in the meal were made.

Discussion

It is obvious from the previous section that two fundamental factors affect the iodine value of linseed oil from the Canadian flax crop. These are the variety of flax grown and the environmental conditions, including climatic factors such as temperature, rainfall, etc., under which the flax is grown. Under present conditions, if a special grade for high iodine value linseed were established, the material that would enter this grade would be largely composed of the variety Redwing with such samples of Bison and Royal as might be grown under favourable environmental conditions.

A consideration of the data on the quality of Western Canadian linseed (2, 3, 4) shows that of the survey samples those having iodine values of 190 units or higher amounted to 4.8% in 1941, 21.5% in 1942, and 33.9% in 1943. An examination of the maps showing the distribution of these samples on the basis of iodine values indicates that, as a general rule, the flax of high iodine value is produced in the northern areas of Alberta, Saskatchewan, and Manitoba. The results for 1943 are particularly striking in that 23 samples having iodine values of 198.0 units or higher were found. An examination of the data for shipping points indicates that the majority of these samples came from the Peace River area in Alberta. In these northern areas Redwing is the variety recommended, since its earliness makes it more suitable for the shorter frost free season. The marked increase in the percentage of samples having iodine values over 190 in the seasons 1942 and 1943 as compared with 1941 and earlier periods can be partially explained on the basis of more moisture and cooler growing conditions over the whole area, but it is largely due to the expansion of flax production into the more northerly sections of the west with a resulting expansion in the quantities of Redwing produced.

If a grade specification for the production of linseed oil having an iodine number of 190 units or higher were established, certain conditions would have to be realized. With the present varieties it is obvious that, to maintain a sufficient volume of production, the expansion of flax growing into the northern sections would have to be maintained and increased. To accomplish this it would be essential that the producer receive an adequate premium for this grade. The history of flax production in Western Canada has shown that this crop tends to be localized in certain areas where conditions are favourable from a production point of view, and, since these areas are not specially adapted to the production of high iodine values, it follows that to stimulate production in other areas a premium would have to be established. In the case of the crushing industry it would be necessary to establish a premium for high iodine value in linseed oil, since the crusher would have to be compensated for increased cost of seed and also to offset a lower return due to lower oil yields and lower protein values in the oil cake.

It would appear that it is doubtful whether a successful separation of the linseed crop on the basis of iodine value could be made under prevailing conditions. However, if Canadian plant breeders are successful in producing a new variety of flax that is adapted to the northern areas and that will produce a high oil yield in addition to high iodine values, it would appear that the premium necessary for the production of a superior grade of linseed might be reduced to a practical level. The progress that is being made toward this objective would indicate that research designed to evaluate the iodine number of linseed oil in terms of specific industries might well be undertaken.

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THE AIR JET METHOD OF DEHULLING SEEDS[1]

By C. R. Fraser[2]

Abstract

Violent agitation of barley, oat, and sunflower seeds in a special container, by means of a jet of compressed air, dehulled the seeds effectively in much less time than the usual dehulling methods and with equal accuracy.

Introduction

In the breeding of such crops as oats, barley, and sunflowers, where the hull is a substantial part of the grain and remains with the kernel when the grain is threshed, it is desirable to know the percentage of hull. The hull is almost worthless as feed and the breeder endeavours to produce varieties that are low in hull percentage. Hull percentage determinations by the usual hand methods are laborious and time consuming, particularly in the case of barley. It would seem that a rapid machine method of hull removal would be very welcome to breeders if such a method was as reliable as the present hand methods. Recently the writer developed a quick, cheap method of hull removal and it is being used very successfully on oats, barley, and sunflowers.

The new method resulted from attempts to speed up the dehulling of barley by blowing the seeds against a wire screen with compressed air. This proved unsatisfactory but when the wire screening was enclosed by a metal cup the results were most gratifying. It was apparent that the use of a jet of compressed air would be a valuable aid in dehulling seeds.

Description of the Method

The new method consists fundamentally of violently agitating the grain while it is enclosed in a metal cup. Compressed air is used for this purpose and reduces the time of dehulling to a fraction of that taken by hand methods. A wire clamp attached to a wooden platform holds the cup in place. The wooden platform may be fastened to a table. The apparatus consists of a metal cup (the one used is $2\frac{1}{4}$ in. long and $2\frac{1}{4}$ in. in diameter) with attachments that are used for barley, oat, and sunflower kernels. One attachment consists of a wire screen that lines the bottom, sides, and top of the cup. The top screen is made to fit snugly over the cup and is easily removed. This is a woven wire screen containing four wires to the inch one way and 14 the other. The screen acts as an abrasive surface in peeling the hulls off barley. Another attachment, used in removing the hulls from sunflower seeds, consists of the wire screen top but no lining in the cup. A third attachment consists of a

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Contribution from the Field Husbandry Department, University of Saskatchewan, Saskatoon, Sask.

[2] *Assistant Technician in Cereal Breeding.*

cardboard lining at the bottom, sides, and top of the cup with no wire contact. The top cardboard is held in place by the wire screen top. This third attachment is used in removing hulls from oats. The hulls of barley are removed by peeling, but those of oats and sunflowers are removed by bombarding the kernels against the sides and bottom of the cup.

Operation

The bombarding of the kernels is done by putting the cup on its side and placing an air jet of about 20 lb. pressure per square inch at the bottom end of the open top of the cup. When the air is turned on, the kernels will fly around in the cup at a terrific speed. As the hulls fall off the kernels the air automatically forces them out through the top screen, leaving clean, fully peeled seed in the cup. Frequently oat kernels are so thin that they may be forced through the top screen and this is not desirable. To remedy this defect a cardboard disk, with a small opening for the air jet, is placed in the top screen and prevents the hulls from flying out. The hulls of oats are fanned out of the kernels after the bombardment has ceased.

This apparatus may be used for determining the percentage kernel in various hulled crops. The desired amount of seed may be weighed out, placed in the cup, and then left to the action of the air jet.

The preliminary treatment and the duration of the air blast, in percentage kernel determinations, varies with the type of crop. Barley seed requires a preliminary soaking. Several grams are weighed out into a small dish. The dish is half filled with water at 130° F. The water is kept at this temperature for 30 to 45 min. The barley seeds, by this time, are quite swollen and the hulls are very soft. The seeds are then placed in the dehulling apparatus and left for 10 or 15 min. During this time the kernels are blown around inside the cup and are continually coming in contact with the wire screen. The hulls catch in the wire screen and are peeled off the kernels. The hulls are then forced out through the top of the top screen by the air jet. After being air-dried the final weight of the sample is taken.

No preliminary treatment of oats is necessary. Several grams of oats may be weighed out and placed in the dehulling apparatus immediately. The air jet is then used for two or three minutes; a longer period may result in damage to the seed and loss of particles knocked off the seed. The kernel weight may be taken immediately.

Owing to variations in air pressure, hull thickness, and humidity, an exact time for the kernel bombardment of oats and barley cannot be stated. Some varieties of oats and barley, such as Banner and Plush, are easily dehulled and the duration of the air blast should be short. Other varieties such as Gopher and Hannchen do not shed their hulls readily and the duration of the air blast should be longer. Large differences in humidity also proved to be important. When the humidity of the laboratory was 10% (in January), the cardboard lining was used for oats. When the laboratory humidity was

55% (in June), a metal lining was substituted for the cardboard lining and the duration of the air blast was increased. The hulls of oats get tougher with increasing humidity. Consequently, the operator must watch the apparatus carefully, especially when oats are being dehulled, in order to ensure peeling with the least possible loss of kernel.

Using the attachment for sunflowers, the procedure is the same as for oats.

Results

The results obtained by the air jet method of peeling showed approximately the same range of variation as those from the hand methods. The air jet results are slightly higher for barley and slightly lower for oats than those obtained by the hand methods.

Where used on barley the air jet method removes the hull less completely than the hand method. The former does not remove all of the hull from the crease of the kernel. In some varieties, such as Hannchen, where the hull is very persistent, parts of it may continue to stick to the kernel even after a long period of bombardment. For most varieties, however, this is not the case. The complete data on barley are presented in Table I and shown graphically in Fig. 2.

From the variance analysis the mean squares were: 0.0127 for varieties, 0.0135 for method, 0.0004 for variety–method interaction, and 0.0005 for

TABLE I

NET WEIGHT OF KERNELS IN GRAMS FROM KNIFE PEELING AND THE AIR JET METHOD AS USED ON COMPARABLE THREE GRAM SAMPLES OF SEVEN VARIETIES OF BARLEY*

Variety	Knife peeling			Air jet method		
	Sample 1	Sample 2	Average	Sample 1	Sample 2	Average
Hannchen (1)	2.65	2.69	2.67	2.70	2.68	2.69
(2)	2.72	2.78	2.75	2.78	2.82	2.80
Newal (1)	2.60	2.59	2.60	2.61	2.66	2.64
(2)	2.70	2.69	2.70	2.72	2.75	2.74
Rex (1)	2.67	2.66	2.66	2.67	2.67	2.67
(2)	2.66	2.66	2.66	2.66	2.67	2.66
Plush (1)	2.59	2.59	2.59	2.62	2.61	2.62
(2)	2.65	2.67	2.66	2.66	2.68	2.67
Prospect (1)	2.53	2.54	2.54	2.61	2.54	2.58
(2)	2.66	2.65	2.66	2.70	2.67	2.68
Regal (1)	2.61	2.69	2.65	2.71	2.66	2.68
(2)	2.62	2.65	2.64	2.67	2.70	2.68
OAC21 (1)	2.54	2.53	2.54	2.61	2.60	2.60
(2)	2.60	2.65	2.62	2.62	2.66	2.64

* *Two sets of results, from samples from two tests, are shown for each variety.*

error. Highly significant differences exist among varieties as well as between methods. The variety–method interaction showed no significance.

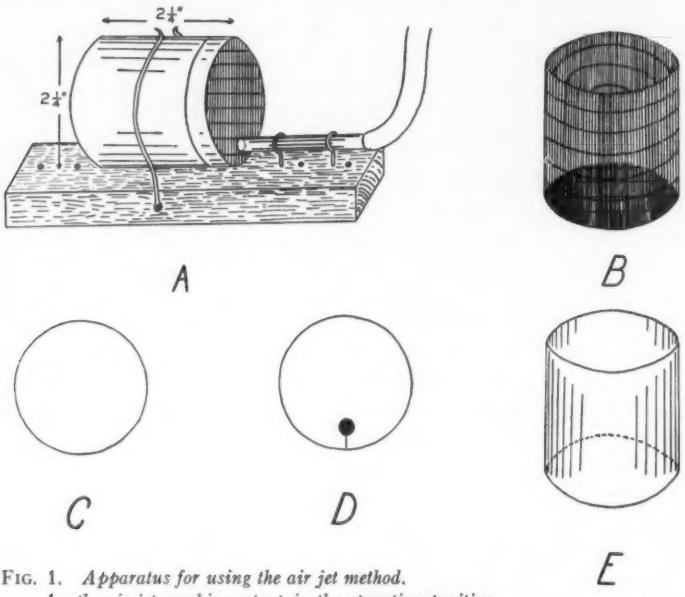

FIG. 1. *Apparatus for using the air jet method.*
A—the air jet machine set up in the operating position.
B—a wire screen lining for the sides and bottom of the cup.
C—a cardboard lining for the bottom of the cup.
D—a cardboard lining for the top of the cup showing the hole cut for the air jet.
E—a cardboard lining for the sides of the cup.

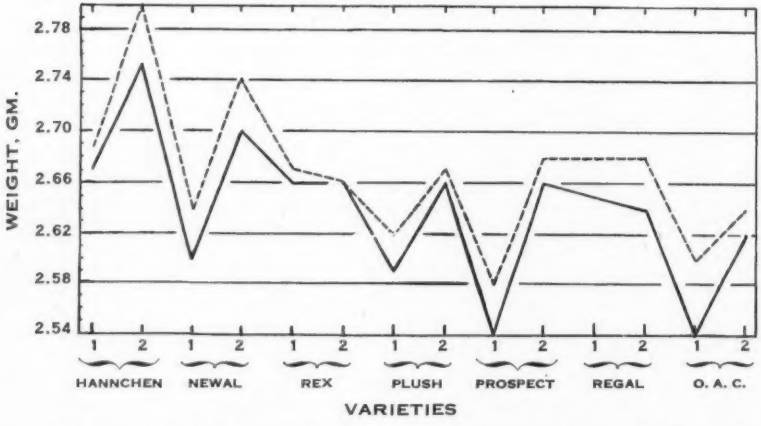

FIG. 2. *Graph showing the relationship between the results from the air jet and hand peeling methods; - - - - air jet method, ——— knife peeling method.*

The results obtained from the air jet method of dehulling oats are lower than those resulting from the hand method. This is due to a small amount of breaking at the tips of the kernels and a subsequent loss of the broken pieces. The oat kernels as a whole also appear slightly polished owing to their contact with the smooth metal cup after being dehulled. This polishing would represent a slightly additional loss. The results on oats are presented in their entirety in Table II and shown graphically in Fig. 3.

TABLE II

NET WEIGHT OF KERNELS IN GRAMS FROM PEELING BY ROLLING WITH A PENCIL AND THE AIR JET METHOD AS USED ON COMPARABLE THREE GRAM SAMPLES OF SEVEN VARIETIES OF OATS*

Variety	Peeling with a pencil			Air jet method		
	Sample 1	Sample 2	Average	Sample 1	Sample 2	Average
Gopher (1)	2.37	2.39	2.38	2.35	2.32	2.34
(2)	2.26	2.27	2.26	2.21	2.25	2.23
Uton (1)	2.38	2.37	2.38	2.35	2.32	2.34
(2)	2.37	2.37	2.37	2.33	2.32	2.32
Valor (1)	2.28	2.31	2.30	2.26	2.27	2.26
(2)	2.25	2.22	2.24	2.18	2.16	2.17
Ajax (1)	2.26	2.25	2.26	2.19	2.15	2.17
(2)	2.25	2.24	2.24	2.15	2.17	2.16
Banner (1)	2.21	2.27	2.24	2.19	2.17	2.18
(2)	2.20	2.27	2.24	2.18	2.20	2.19
Exeter (1)	2.22	2.25	2.24	2.23	2.21	2.22
(2)	2.22	2.24	2.23	2.20	2.22	2.21
Victory (1)	2.25	2.21	2.23	2.18	2.22	2.20
(2)	2.22	2.24	2.23	2.22	2.20	2.21

* *Two sets of results, from samples from two tests, are shown for each variety.*

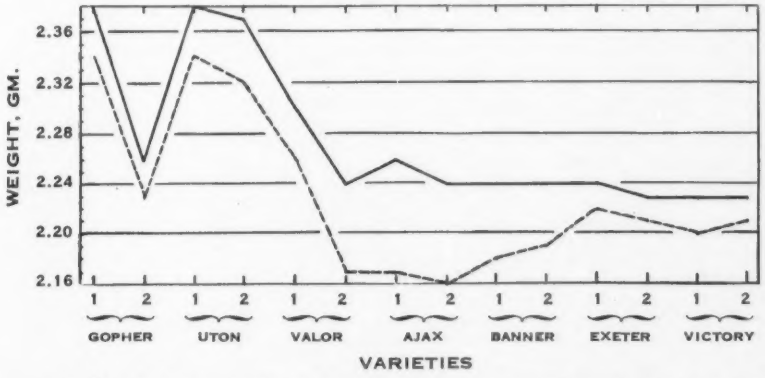

FIG. 3. *Graph showing the relationship between the results from the air jet and pencil methods of dehulling;* - - - - *air jet method,* ———— *pencil peeling method.*

From the variance analysis the mean squares were: 0.0139 for varieties, 0.0275 for method, 0.0005 for variety–method interaction, and 0.0004 for error. The differences among varieties and between methods are highly significant. The variety–method interaction showed no significance.

No results have been tabulated for percentage kernel determinations of sunflower varieties. Our neighbouring laboratory, the Dominion Forage Crops Laboratory, is now using this method successfully in percentage kernel determinations.

Conclusion

Since, for both oats and barley, there was no significant difference in the variety–method interaction, either the hand methods or the air jet method could be used with equal accuracy in making percentage kernel determinations on these crops. The air jet method of removing the hulls from kernels may prove to be a great time and labour saver in grain research and plant breeding laboratories. It is also quite possible that the air jet principle may have distinct value for commercial use.

Acknowledgment

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